Final Technical Report

Earthquake Hazard Mapping for Oregon Communities

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Ian. P Madin, Zhenming Wang
Oregon Department of Geology and Mineral Industries
800 NE Oregon St. #28
Portland, OR 97232
503 731 4100
503 731 4066 (Fax)
Ian.P.Madin@state.or.us

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Abstract

This project has developed maps of site and soil dependent earthquake hazards for 28 Oregon urban areas (including 44 incorporated cities) using archival geologic data and measured in-situ shear- wave velocity data.

Our method is to build a GIS-based three-dimensional geologic model from surface and subsurface geologic data, and then combine that geologic model with shear wave velocity data. Shear wave velocities are obtained in each urban area by shear wave refraction measurements from a hammer source. The velocities and geologic models are used to calculate the average shear wave velocity of the upper 30m at each site, and that value is used to assign the site to a UBC 1997 soil type.

Liquefaction hazards are assessed using information about the age and grain size of each unit in the model, its thickness, and average shear wave velocity. Each area is assigned a liquefaction hazard category based on these parameters.

Earthquake-induced landslide hazards are assessed simply by using slope models derived from 30 m DEM data and geologic mapping of existing landslides. Each area is assigned a slope failure hazard based on these parameters.

Relative earthquake hazard maps are defined by assigning comparable values to the 3 or 4 hazard classes generated for each of the three hazards above, then combining those hazards as the square root of the sum of the squares. The resultant hazard map shows which areas have the greatest aggregate hazard, and allows comparison of these areas to each other and to other areas in Oregon for which the same type of map exists.

The pattern of hazards across the study area is not unexpected. Southern Oregon communities with thin Quaternary deposits and high velocity pre-Tertiary bedrock have generally low hazards in all categories and consequent low Relative hazard. Communities in the Willamette Valley of western Oregon have moderate levels of individual hazard due to thick Quaternary silt and gravel deposits and moderate Relative hazard. Oregon coastal communities have generally moderate to high levels of individual hazard,

and moderate to high Relative hazard, reflecting thick deposits of Holocene coastal sand and estuarine deposits.

Introduction

This project was designed to provide cost effective mapping of site-dependent earthquake hazards for numerous mid-sized Oregon communities. The Oregon Department of Geology (DOGAMI) has produced site-dependent earthquake hazard maps for several of the major population centers in Oregon such as Portland and Salem (Mabey and others, 1997; Wang and Leonard, 1995). DOGAMI is currently producing hazard maps for the Eugene and Klamath Falls urban areas, and plans to complete the Medford, Corvallis-Albany, and Coos Bay areas in the next four years. However, the remaining urban areas in Oregon are too small (population less than 40k) to warrant the expense ($100-200K) of a full hazard mapping program with extensive field work and geotechnical sampling. With this project we are seeking to find a quick and inexpensive way to produce credible hazard maps for smaller communities, which would otherwise have no assessment of the hazard available. We selected all Oregon communities that were in UBC Seismic Zone 3, had populations greater than 4,000 people, and did not have a full-scale hazard mapping program planned. Figure 1 shows the resultant set of communities. As originally proposed, the project was to use existing data to build geologic models and archival geotechnical and shear-wave velocity data to estimate conditions in the study areas. After the project was contracted, we acquired the expertise to collect in situ shear-wave velocity data rapidly and inexpensively through shear-wave refraction techniques. Therefore, at our expense, we augmented the original program by collecting shear wave velocity data at several sites within each study area.

Each community in Oregon has, by state law, an Urban Growth Boundary, outside of which development is generally restricted to very low density residential or agricultural. These boundaries are revised every 15 years. We arrived at as the study area for each community by adding a 1-Km buffer to the urban growth boundaries of each community or group of communities. We believe that this area will cover all conceivable urban development for the coming 30 years.

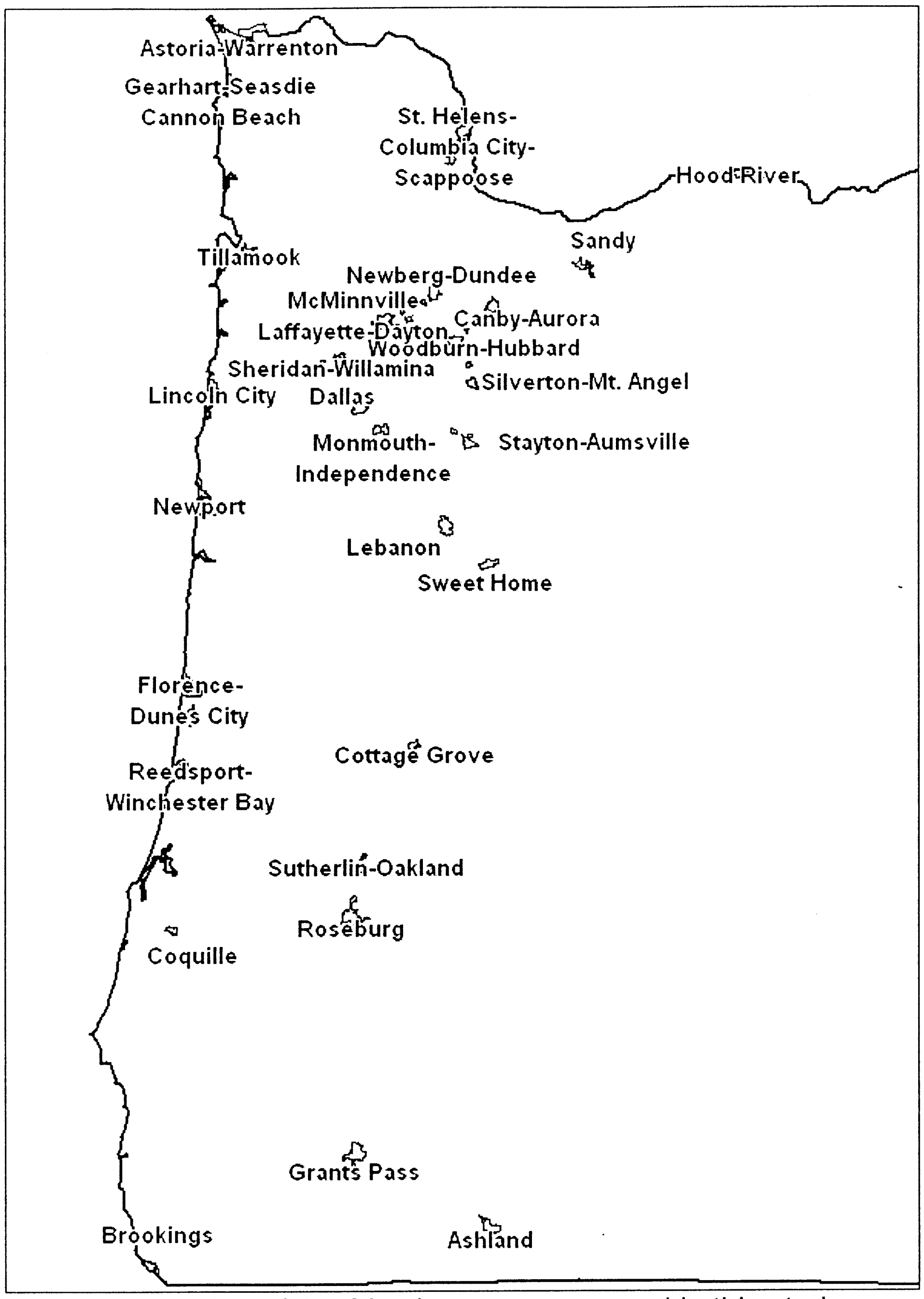

Figure 1. Location of the 28 urban areas mapped in this study.

The final result of this study is a set of three publications covering the 28 urban areas. Because of the large number of color maps involved, it was necessary to break the study into smaller pieces to avoid spending lots of money to produce numerous maps in each publication that would be of little interest to most users. We divided the urban areas into publications by groups of counties, resulting in the set of publications listed below:

Madin, I. P., and Wang, Z., 1999, Earthquake Hazard Maps for selected Urban Areas in Curry, Douglas, Jackson, Josephine and Lane Counties, Oregon: Oregon Department of Geology and Mineral Industries IMS-7

Madin, I. P., and Wang, Z., 1999, Earthquake Hazard Maps for selected Urban Areas in Columbia, Clackamas, Hood River, Linn and Marion Counties, Oregon: Oregon Department of Geology and Mineral Industries IMS-8

Madin, I. P., and Wang, Z., 1999, Earthquake Hazard Maps for selected Urban Areas in Clatsop, Lincoln, Polk, Tillamook and Yamhill Counties, Oregon: Oregon Department of Geology and Mineral Industries IMS-9

Each publication includes the following:
1. Identical Report describing map-making methodology and map uses.
2. Identical Appendix describing geologic units, shear wave velocity collection methods, shear wave velocity data.
3. Short summaries describing the geology and hazard distribution for each of the included urban areas.
4. Hard-copy color Relative hazard maps for each of the included areas.
5. CD-ROM with .jpg images of the three individual hazard maps for each included area, and vector files with the hazard zone polygons.

These publications are in press starting mid March of 1999, and should be available in April or May of 1999. At that time, in addition to providing copies to USGS as required under this contract, we will provide free copies to the administrators of each included city and county. The remainder of the publications will be sold to the public through our public information outlets.

For this final report to USGS we provide the following:

1. The standard text and Appendix from the publications.
2. All of the urban area summaries.
3. Study-wide color maps of each of the hazard types.

Standard Report Text

This is one of three companion publications presenting earthquake hazard maps for intermediate sized Western Oregon communities. Each publication covers selected urban areas in a geographic region of the state.

INTRODUCTION

Since the late 1980's there has been a significant increase in the understanding of earthquake hazards in the Pacific Northwest. It is now known that Oregon may experience damaging earthquakes much larger than any that have past (Atwater, 1987; Heaton and Hartzell, 1987; Weaver and Shedlock, 1989; Yelin and others, 1994). Planning to respond to earthquake disasters and strengthening homes, buildings and power, water, communication and transportation lifelines can greatly reduce the impact of an earthquake. These measures should be based on the best possible forecast of the amount and distribution of future earthquake damage. Earthquake hazard maps such as those in this publication provide such a forecast.

The amount of damage sustained by a building during a strong earthquake is difficult to predict and depends on the size, type and location of the earthquake, the characteristics of the soils at the building site, and the characteristics of the building itself. At present, it is not possible to accurately forecast the location or size of future earthquakes. It is possible however to predict the behavior of the soil (in this report soil means the relatively loose and soft geologic materials that typically overlie solid bedrock in western Oregon) at any particular site. In fact in many major earthquakes around the world, a large amount of the damage has been due to the behavior of the soil.

These maps identify those areas in selected Oregon communities that will suffer more damage, relative to other areas, during a damaging earthquake. The analysis is based on the behavior of the soils, and does not depict the absolute earthquake hazard at any particular site. It is quite possible that, for any given earthquake, damage in even the highest hazard areas will be light. On the other hand, during an earthquake that is stronger or much closer than our design parameters, even the lowest hazard categories could experience severe damage.

This report includes a non-technical description of how the maps were made and how they might be used. More technical information on the map making methods is contained in the Appendix. The report includes hard copy Relative Earthquake Hazard Maps for each urban area, printed on a USGS topographic base map. The scale of these maps varies from 1:24,000 to 1:30,000, depending on the size of the map area with respect to the page size of the publication. For each area, three individual hazard component maps are included as digital data on CD-ROM. The digital data consists of high resolution .TIF files (bitmap images) that can be viewed with most image viewers or word processors, and as MapInfo® and ArcInfo® format GIS vector files.

These maps were produced by the Oregon Department of Geology and Mineral Industries and were funded by the State of Oregon and the U.S. Geological Survey (USGS) Department of the Interior, under USGS award #1434-97-GR-03118. The views and conclusions contained in this document are

those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

EARTHQUAKE HAZARD

Earthquakes from three different sources threaten communities in western Oregon (Figure 1). These sources are crustal, intraplate, and subduction zone earthquakes. The most common are crustal earthquakes, which typically occur in the North American plate above the subduction zone at relatively shallow depths of 6-12 mi (10-20 km) below the surface. The Scotts Mills (M 5.6) (Madin and others, 1993) and the Klamath Falls main shocks (M 5.9 and M 6.0) (Wiley and others, 1993) of 1993 were crustal earthquakes.

Deeper intraplate earthquakes occur within the remains of the ocean floor (the Juan de Fuca plate) that has been subducted beneath North America. Intraplate earthquakes caused damage in the Puget Sound region in 1949 and again in 1965. This type of earthquake could occur beneath much of western Oregon at depths of 25-37 mi (40-60 km).

Great subduction zone earthquakes occur around the world where the plates that make up the surface of the earth collide. When the plates collide, one plate slides (subducts) beneath the other, where it is reabsorbed into the mantle. This dipping interface between the two plates is the site of some of the most powerful earthquakes ever recorded, often having magnitudes of 8 to 9 on the moment magnitude scale. The 1960 Chilean (M 9.5) and the 1964 Great Alaska (M 9.2) earthquakes were subduction zone earthquakes (Kanamori, 1977). The Cascadia Subduction Zone, which lies off the Oregon and Washington coasts, has been recognized for many years. There have been no earthquakes on the Cascadia Subduction Zone during our short 200-year historical record. However, in the past several years, a variety of studies have found widespread evidence that very large earthquakes have occurred repeatedly in the past, most recently about 300 years ago in January 1700 (Atwater, 1987; Yamaguchi and others, 1997). The best available evidence indicates that these earthquakes occur, on average, every 500 to 540 years with an interval between individual events that ranges from 100-300 years to about 1000 years (Atwater and Hemphill-Haley, 1997). There is every reason to believe that they will continue to occur in the future.

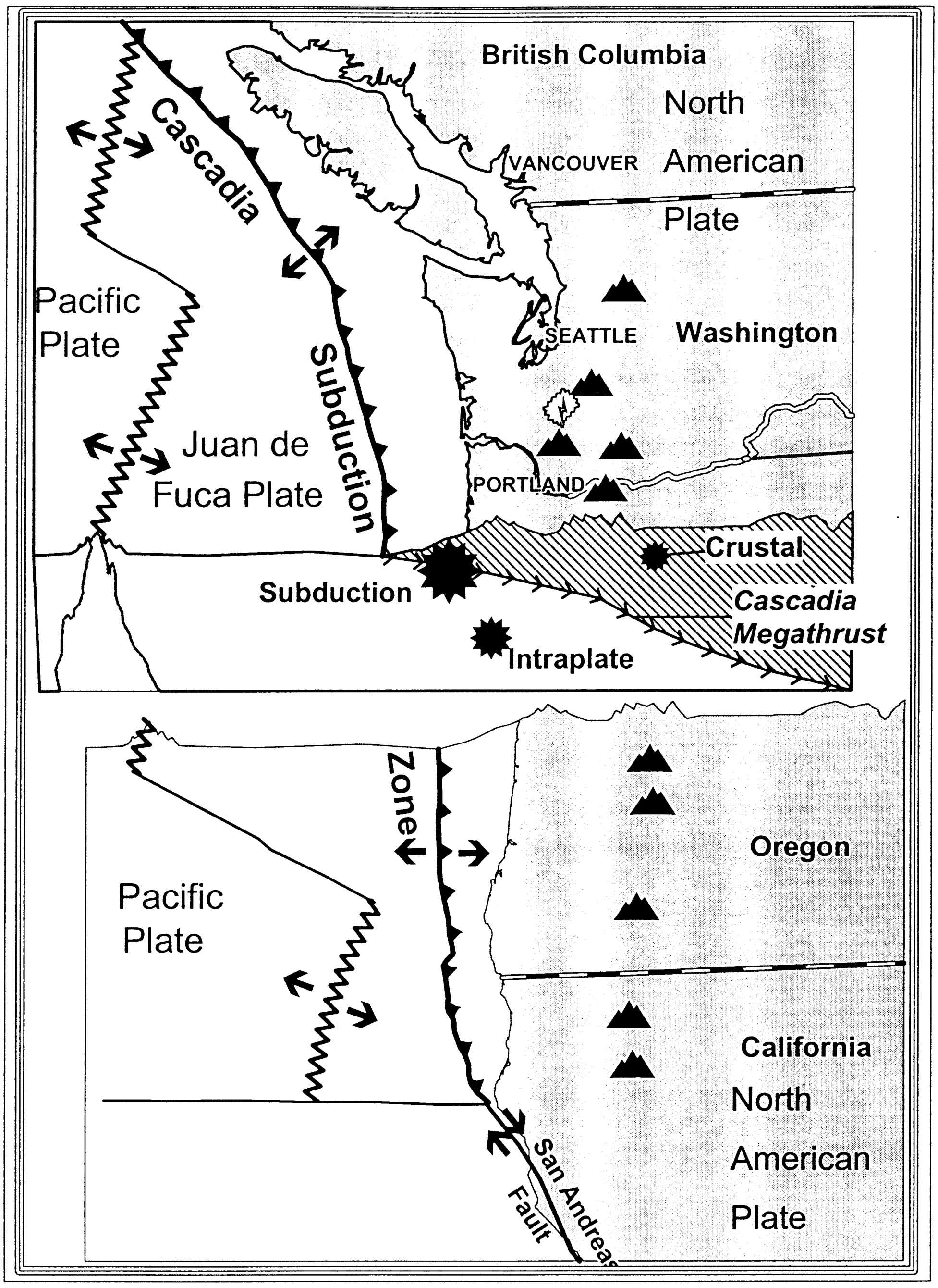

Figure 1.

Plate tectonic map of the Pacific Northwest. Oregon is cut in half to show where earthquakes originate below the surface.

Together these three types of earthquakes could cause strong shaking through most of western Oregon. Maps are available that forecast the likely strength of shaking for all of Oregon (Geomatrix, 1995; Madin and Mabey, 1996;

Frankel and others, 1996). However, these maps show the expected strength of shaking at a firm site on bedrock and do not include the significant influence of soil on the strength of shaking. These maps forecast a uniform level of shaking and damage in most communities, and as such they do not provide a useful tool for planning earthquake hazard mitigation measures.

EARTHQUAKE EFFECTS

Damaging earthquakes will occur in the cities and towns of western Oregon. This fact was demonstrated by the Scotts Mills earthquake (M 5.6) in 1993 (Madin and others, 1993). Although we cannot predict when the next damaging earthquake will strike, where it will occur, or how large it will be, we can evaluate the influence of site geology on potential earthquake damage. This evaluation can occur reliably even though the exact sources of earthquake shaking are uncertain.

The most severe damage done by an earthquake is commonly localized. One or more of the following phenomena generally causes the damage in these areas:

1) Amplification of ground shaking by a “soft” soil column.

2) Liquefaction of water-saturated sand, silt, or gravel creating areas of “quicksand”.

3) Landslides triggered by shaking, even on relatively gentle slopes.

These effects can be evaluated before the earthquake occurs if data are available on the thickness and nature of the geologic materials and soils at the site (Bolt, 1993). The exact nature and magnitude of these effects are useful to technical professionals, and these data (in digital format) are included in this publication. For others, what is more significant is that these effects increase the damage caused by an earthquake and localize the most severe damage.

HAZARD MAP METHODOLOGY

SELECTION OF MAP AREAS

Urban Areas were mapped if they had a population greater than 4000, were in Uniform Building Code (UBC) Seismic Zone 3 or 4, and were not likely to be the subject of a more detailed future hazard mapping program. The goal of this project was to provide an inexpensive general hazard assessment for small communities that could not afford their own mapping program, but were not large enough to justify a major state-funded mapping effort. Such full-scale projects have been undertaken for the Portland, Salem, Eugene and Klamath Falls urban areas, and typically take several years and cost several hundred thousand dollars. In contrast, this project involved about two weeks of work and a few thousand dollars for each urban area mapped.

For each urban area selected, the map area was defined by a 3300 ft (1 km)-wide buffer around the outside of the urban growth boundary.

Geologic Model

The most important element of any earthquake hazard evaluation is the development of a three-dimensional geologic model. For analysis of the amplification and liquefaction hazards, the most important feature is the thickness of the loose sand, silt and gravel deposits that usually overlie firm bedrock. For analysis of the landslide hazard, the steepness of the slopes and presence of existing landslides is important. For each urban area, the geologic model was developed as follows;

1. The best available geologic mapping was used to determine what geologic materials were present, and where they occur. Air photos were used to help make these decisions were the mapping was poor, or of low resolutions. All data was plotted digitally on USGS Digital Raster Graphics (DRG) maps (the digital equivalent of USGS 1:24,000 scale topographic maps).

2. Drillers' logs of approximately-located water wells were examined to determine the geology beneath the surface, and map the thickness of the loose surficial deposits and the depth to firm bedrock. Water wells were located by using the location information provided on the logs, which often are only accurate to about a thousand feet. Field location of the individual logs would have been prohibitively expensive.

3. The water well data was used with the surface data to produce a three-dimensional geologic model, describing the thickness of the various geologic materials in the top 100 ft (30 m) throughout each urban area. MapInfo ™ and Vertical Mapper ™ Geographic Information System (GIS) software were used. The models take the form of a grid of thickness values spaced every 165 ft (50m).

4. The resultant models were reviewed by geologist knowledgeable about each area, who were asked to judge whether the models were reasonable and consistent with the data.

5. Existing landslides were mapped where depicted on existing geologic maps, and where air photos showed clear signs of landslide topography.

6. Slope data was derived from USGS Digital Elevations Models (DEM's) with elevation data every 100 ft (30 m). MapInfo® and Vertical Mapper® were used to map the steepness of slopes using the DEM data.

The details of the local geology and data sources for each urban area are described in the Urban Area Summaries section of this report.

Hazard Analysis

GROUND SHAKING AMPLIFICATION

The soils and soft sedimentary rocks near the surface can modify bedrock ground shaking caused by an earthquake. This modification can increase (or decrease) the strength of shaking or change the frequency of the shaking. The nature of the modifications is determined by the thickness of the geologic materials and their physical properties, such as stiffness.

This amplification study uses a method first developed for the National Earthquake Hazard Reduction Program (NEHRP) and published by the Federal Emergency Management Agency (FEMA, 1995). This method was adopted in the 1997 version of the Uniform Building Code (International Conference of Building Officials, 1997) and will henceforth be referred to as the UBC-97 methodology. The UBC-97 methodology defines six soil categories based on average shear-wave velocity in the upper 100 ft (30 m) of the soil column. The shear wave velocity is the speed with which a particular type of ground vibration travels through a material, and can be measured directly by several techniques. The six soil categories are Hard Rock (A), Rock (B), Very Dense Soil and Soft Rock (C), Stiff Soil Profile (D), Soft Soil Profile (E), and Special Soils (F). Category F soils are very soft soils requiring site specific evaluation, and are not mapped in this study because limited funding precluded any site visits.

For the amplification hazard component maps, we collected shear wave velocity data (see Appendices for data and methods) at one or more sites in each urban area, and used our geologic model to calculate the average shear wave velocity of each 165 ft (50 m) grid cell in the model. We then assigned a soil category using the relationships in Table 1.

Table 1. UBC-97 soil profile types

Soil Category	Description	Average shear-wave velocity meters/second	Amplification Factor (Cv)
S_A	Hard rock	**Vs** > 1500	0.8
S_B	Rock	760 < **Vs** < 1500	1
S_C	Very dense soil and soft rock	360 < **Vs** < 760	1.5
S_D	Stiff soil	180 < **Vs** < 360	1.8
S_E	Soil	**Vs** < 180	2.8
S_F	Soil requiring site-specific evaluation		

Using the UBC-97 methodology, none of the urban areas in this study had Type A soils. UBC-97 Soil Category maps for each urban area are presented in the accompanying digital map set.

LIQUEFACTION

Liquefaction is a phenomenon in which shaking of a saturated soil causes its material properties to change so that it behaves as a liquid. In qualitative terms, the cause of liquefaction was described very well by Seed and Idriss (1982): “If a saturated sand is subjected to ground vibrations, it tends to compact and decrease in volume; if drainage is unable to occur, the tendency to decrease in volume results in an increase in pore water pressure, and if the pore water pressure builds up to the point at which it is equal to the overburden pressure, the effective stress becomes zero, the sand loses its strength completely, and it develops a liquefied state."

Soils that liquefy tend to be young, loose, granular soils that are saturated with water (National Research Council, 1985). Unsaturated soils will not liquefy, but they may settle. If an earthquake induces liquefaction, several things can happen. The liquefied layer and everything lying on top of it may move downslope. Alternatively, it may oscillate with displacements large enough to rupture pipelines, move bridge abutments, or rupture building foundations. Light objects, such as underground storage tanks can float toward the surface, and heavy objects, such as buildings, can sink. Typical displacements can range from centimeters to meters. Thus, if the soil at a site liquefies, the damage resulting from an earthquake can be dramatically increased over what shaking alone might have caused.

The liquefaction hazard analysis is based on the age and grain size of the geologic unit, the thickness of the unit, and the shear wave velocity. Use of the shear wave velocity to characterize the liquefaction potential follows Andrus and Stokoe (1997). Liquefaction hazard categories were assigned according to Table 3. In all communities we assumed that the susceptible units were saturated. This is reasonable and conservative since most of the susceptible units are either alluvial deposits in floodplains, coastal deposits, or silt deposits in areas of low relief and high rainfall in the Willamette Valley.

Table 3. Liquefaction Hazard Categories

Shear Wave velocity meters/second	Geologic Units (See Appendix)			
	Qs, Qe, Qaf	Qmf, Qmf1, Qmf2, QPe, Qmt	Qac,QTac, QTaf, Qmg	Tbs, Tbv, Kjg, Kjm
greater than 200	Moderate	Low	None	None
100 m/s to 200	High	Moderate	Low	None
less than 100	High	High	Moderate	None

Thickness Adjustment	
Unit Thickness (meters)	
less than 0.5	down 2 categories
0.5 to 3.0	down 1 category
greater than 3.0	no change

EARTHQUAKE-INDUCED LANDSLIDE ANALYSIS

The hazard due to earthquake-induced landsliding was assessed using slope data derived from USGS DEM's with 100 ft (30m) data spacing, and mapping of existing slides, either from air photo interpretation or published geologic maps. The analysis was based on methods used by Wang and others (1998) and Wang (1999), but was greatly simplified because there was no field data available. Earthquake-induced landsliding hazard categories were assigned according to table 3.

Table 3. Earthquake-Induced Landslide Hazard Zones

Slope angle (degrees)		Hazard Category
Less than 5		Low
5 to 25		Medium
greater than 25		High
Existing Landslides		High

RELATIVE EARTHQUAKE HAZARD MAPS

The *Relative Earthquake Hazard Map* is a composite hazard map depicting the relative hazard at any site due to the combination of the effects mentioned above. It delineates those areas that are most likely to experience the most severe effects during a damaging earthquake. Areas of highest risk are those with high ground amplification, high likelihood of liquefaction, existing landslides, or slopes steeper than 25 degrees. Planners, lenders, insurers, and emergency responders can use these simple composite hazard maps for first-order hazard mitigation and response planning. It is very important to note that the relative hazard map predicts the tendency of a site to have greater or lesser damage than other sites in the area. These zones, however, should not be used as the sole basis for any type of restrictive or exclusionary development policy.

The *Relative Earthquake Hazard Maps were* created to show which areas will have the greatest tendency to experience damage due to any combination of the three hazards described above. For the purpose of creating the final relative hazard map for each urban area, the zones in each of the three component maps were assigned numerical values according to Table 4. For every point (using a 165 ft {30m} grid spacing) on the map the zone rating for each individual was squared, and the resulting numbers were added together. Then the square root of this sum was taken and rounded to the nearest whole number. A result of 4 or more is assigned to category A, 3 to category B, 2 to category C, and 1 to category D. While the production of the individual hazard maps is different from previous DOGAMI relative earthquake studies (Mabey and others, 1997; Wang and Leonard, 1996; Wang and Priest, 1995), the method of production of the final relative hazard map is very similar. Thus these relative hazard maps are directly comparable to previous DOGAMI studies in Eugene-Springfield, Portland, Salem and Siletz Bay.

Table 4.

Hazard Zone Values used in the Relative Hazard Maps

Relative Hazard Zone	Amplification UBC-97 Category	Liquefaction Likelihood of Liquefaction	Landslides Likelihood of earthquake induced landslide
0	**B**	**None**	**None**
1	**C**	**Low**	
1.5			**Medium**
2	**D**	**Medium**	
3	**E**	**High**	**High**

The GIS techniques used to develop these maps involved several changes between vector data and raster data, with a data grid cell size of 165 ft (50m) for the raster data. As a result, the Relative Hazard maps often had numerous zones that were very small, and probably not significant. The final maps were hand-edited to remove all hazard zones that covered less than 1 acre.

USE OF THE RELATIVE EARTHQUAKE HAZARD MAPS

The *Relative Earthquake Hazard Maps* delineate those areas most likely to experience damage in a given earthquake. This information can be used to develop a variety of hazard mitigation strategies. This information, however, should be carefully considered and understood in order to avoid inappropriate use.

Emergency Response and Hazard Mitigation

One of the key uses of these maps is to develop emergency response plans. The areas indicated as having higher hazard would be the areas where the greatest and most abundant damage will tend to occur. Planning for disaster response will be enhanced by the use of these maps to identify which resources and transportation routes are likely to be damaged .

Land-use Planning and Seismic Retrofit

Efforts and funds for both urban renewal and strengthening or replacing older and weaker buildings can be focused on the areas where the effects of earthquakes will be the greatest. The location of future urban expansion or intensified development should consider earthquake hazards.

Requirements placed on development could be based on the hazard zone in which the development is located. For example, the type of site-specific earthquake hazard investigation that is required could be based on the hazard

Lifelines

Lifelines include road and access systems including railroads, airports and runways, bridges, and over and under passes; as well as utilities and distribution systems. The *Relative Earthquake Hazard Map* and its component single-hazard maps are especially useful for expected damage estimation and mitigation for lifelines. The distributed character of often requires regional as opposed to site-specific hazard assessments. These hazard maps allow quantitative estimates of the hazard throughout a lifeline system. This information can be used for assessing vulnerability as well as indicating priorities and approaches for mitigation.

Engineering

The hazard zones shown on the Relative Earthquake Hazard Maps are not a substitute for site-specific evaluations based on subsurface information gathered at a site. The calculated values of the individual component maps used to make the Relative Hazard Maps may, however, be used to good purpose in the absence of such site-specific information, such as at the feasibility study or preliminary design stage. In most cases, the quantitative values calculated for these maps would be superior to a qualitative estimate based solely on lithology or non site-specific information. Any significant deviation of observed site geology from the geologic model used in the analyses indicates the need for additional analyses at the site.

Relative Hazard

It is important to recognize the limitations of the *Relative Earthquake Hazard Map*, which in no way includes information with regard to the probability of damage occurring. Rather, it shows that when shaking occurs, the damage is more likely to occur, or be more severe in, the higher hazard areas. The exact probability of such shaking occurring is yet to be determined.

Neither should the higher hazard areas be viewed as unsafe. Except for landslides, the earthquake effects that are factored into the *Relative Earthquake Hazard Map* are not life threatening in and of themselves. What is life threatening is the way that structures such as buildings and bridges respond to these effects. Locations are not necessarily unsafe or even less safe, but the structures there may be.

The map depicts trends and tendencies. In all cases, the actual threat at a given location can be assessed only by some degree of site-specific assessment. This is similar to being able to say demographically that a zip code zone contains an economic middle class, but within that zone there easily could be individuals or neighborhoods significantly richer or poorer.

Because the maps exist as "layers" of digital GIS data, they can easily be combined with earthquake source information to produce earthquake damage scenarios. The map can also be combined with probabilistic or scenario bedrock ground shaking maps to provide an assessment of the absolute level of hazard and an estimate of how often that level will occur. Finally, the maps can also be easily incorporated with GIS data for land-use or emergency management planning.

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STANDARD APPENDIX

CONTENTS

1. Generalized Descriptions of geologic units used in this report

2. Data Table showing Shear-Wave velocities measured for geologic units in each community.

3. Description of shear-wave velocity collection methodology

4. Index of digital files on accompanying CD-ROM

GEOLOGIC UNITS USED IN TABLE A-1

Qaf Fine-grained Quaternary Alluvium, river and stream deposits of sand, silt and clay

Qac Coarse Grained Quaternary Alluvium, river and stream deposits of sand and gravel

Qmf Fine-grained Quaternary Missoula Flood deposits, sand and silt left by catastrophic glacial floods

Qmc Coarse–grained Quaternary Missoula Flood deposits, sand and gravel left by catastrophic glacial floods

Qmf1 Fine-grained Quaternary Missoula Flood deposits, upper, oxidized low velocity layer

Qmf2 Fine-grained Quaternary Missoula Flood deposits, lower, reduced high velocity layer

Qe Quaternary estuarine sediments, silt, sand and mud deposited in bays and tidewater of major rivers

Qs Quaternary sands, beach and dune deposits along the coast

Qmt Quaternary Marine Terrace deposits, sand and silt deposited during previous interglacial periods.

QPe Pleistocene estuarine sediments, older sand and mud deposited in bays and tidewater reaches of rivers

QTac Older coarse-grained alluvium, sand and gravel deposited by ancient rivers and streams

QTaf Older fine-grained alluvium, sand and silt deposited by ancient rivers and streams

Grus Decomposed granite

Tbs Sedimentary bedrock

Tbv Volcanic bedrock

KJg Granite bedrock

KJM Metamorphic bedrock

TABLE A-1, MEASURED SHEAR WAVE VELOCITIES.

URBAN AREA	SITE #	LAT	LONG	T-1	V-1	U-1	T-2	V-2	U-2	T-3	V-3	U-3	T-4	V-4	U-4
Ashland	Ashl01	42.2084	-122.7127	2.0	194	Qaf	6.2	720	grus	0.0	1220	Kjg	0.0	0	
Ashland	Ashl02	42.1912	-122.6857	8.5	327	Qac	13.5	640	grus	0.0	1015	Kjg	0.0	0	
Astoria	Ast01	46.1889	-123.8169	10.0	181	Qs	0.0	523	Tbs	0.0	0		0.0	0	
Astoria	Ast02	46.1553	-123.8254	5.0	70	Qe	0.0	133	Qs	0.0	0		0.0	0	
Astoria	Ast03	46.1530	-123.8877	8.2	81	Qe	0.0	151	Qs	0.0	0		0.0	0	
Warrenton	War02	46.2049	-123.9516	0.0	190	Qs	0.0	0		0.0	0		0.0	0	
Warrenton	War01	46.1724	-123.9209	5.5	95	Qe	0.0	210	Qs	0.0	0		0.0	0	
Brookings	Brook01	42.0570	-124.2809	0.0	183	nd	6.0	481	Qmt	0.0	1172	Kjm	0.0	0	
Canby-Aurora	Canb01	45.2682	-122.6859	2.5	266	Qmf	0.0	680	Qmc	0.0	0		0.0	0	
Canby-Aurora	Canb02	45.2550	-122.6979	3.5	160	Qmf	0.0	657	Qmc	0.0	0		0.0	0	
Coquille	Coquil01	43.1854	-124.1941	9.5	191	Qaf	0.0	385	Tbs	0.0	0		0.0	0	
Coquille	Coquil02	43.1759	-124.1981	27.0	151	Qaf	0.0	589	Tbs	0.0	0		0.0	0	
Cottage Grove	Cottage01	43.7856	-123.0651	3.4	219	Qac	0.0	973	Tbs	0.0	0		0.0	0	
Cottage Grove	Cottage02	43.7968	-123.0331	3.6	187	Qac	0.0	1270	Tbs	0.0	0		0.0	0	
Dallas	Dalla01	44.9287	-123.3222	3.4	165	Qmf	0.0	755	Tbs	0.0	0		0.0	0	
Dallas	Dalla02	44.9218	-123.3001	2.7	174	Qmf	0.0	780	Tbs	0.0	0		0.0	0	
Hood River	Hoodr01	45.7057	-121.5268	4.5	145	Qaf	0.0	1352	Tbv	0.0	0		0.0	0	
Hood River	Hoodr02	45.6893	-121.5190	1.0	139	nd	6.0	271	QTac	38.0	377	QTac	0.0	995	Tbv
Lebanon	Lebanon01	44.5293	-122.9104	3.0	144	Qac	0.0	598	Tbv	0.0	0		0.0	0	
Lebanon	Lebanon02	44.5517	-122.8945	4.9	244	QTac	0.0	665	Tbv	0.0	0		0.0	0	
MCMinnville-Dayton	McMin01	45.2052	-123.2321	5.8	180	Qmf1	0.0	1371	Tbv	0.0	0		0.0	0	
MCMinnville-Dayton	McMin02	45.2112	-123.1383	7.0	201	Qmf1	0.0	277	Qmf2	0.0	0		0.0	0	
MCMinnville-Dayton	McMin03	45.2290	-123.0655	5.6	213	Qmf1	31.7	241	Qmf2	25.3	460	QTaf	0.0	914	Tbs
Monmouth-Independence	Monm1	44.8649	-123.2181	2.3	169	Qmf	15.0	325	Qac	29.1	550	QTaf	0.0	1138	Tbv
Monmouth-Independence	Monm2	44.8425	-123.2027	7.0	159	Qmf	21.1	275	Qac	0.0	403	QTaf	0.0	0	
Reedsport-Wincheser Bay	Reedp01	43.7179	-124.0914	6.4	89	Qe	8.5	144	QPe	0.0	262	QPe	0.0	0	
Reedsport-Wincheser Bay	Reedp02	43.6919	-124.1220	3.9	142	QPe	0.0	749	Tbs	0.0	0		0.0	0	
Roseburg	Roseb01	43.2159	-123.3668	6.0	181	Qac	0.0	944	Tbv	0.0	0		0.0	0	
Sheridan	Sher01	45.0948	-123.3898	3.4	125	Qmf	0.0	749	Tbs	0.0	0		0.0	0	
Willamina	Willa01	45.0769	-123.4811	1.0	124	Qmf	3.0	386	QTaf	0.0	773	Tbs	0.0	0	
Mt. Angel	Mtag01	45.0731	-122.7897	3.7	184	Qmf	10.0	438	QTac	0.0	1087	Tbv	0.0	0	
Silverton	Silvert01	45.0166	-122.7881	1.0	196	Qmf	3.0	818	QTaf	0.0	1402	Tbv	0.0	0	
St. Helens-Scappoose	STH01	45.8516	-122.8104	1.0	88	Qaf	0.0	1204	Tbv	0.0	0		0.0	0	
St. Helens-Scappoose	STH02	45.8562	-122.8364	1.0	40	nd	0.0	830	Qac	0.0	0		0.0	0	
St. Helens-Scappoose	STH03	45.8619	-122.7992	1.5	132	Qaf	0.0	710	Qac	0.0	0		0.0	0	
Stayton	Stayt01	44.8311	-122.7879	3.0	216	nd	0.0	551	Tbv	0.0	0		0.0	0	
Stayton	Stayt02	44.8047	-122.8014	1.8	142	Qac	0.0	958	Tbv	0.0	0		0.0	0	
Sutherlin	Sutherl01	43.3822	-123.3306	5.0	426	Qaf	0.0	842	Tbs	0.0	0		0.0	0	
Oakland	Oakland1	43.4221	-123.2988	9.1	198	Qaf	0.0	1079	Tbs	0.0	0		0.0	0	

Sweet Home	Sweet01	44.3955	-122.7234	6.1	203	Qac	0.0	855	Tbv	0.0	0		0.0	0	
Woodburn-Hubbard	Hub01	45.1871	-122.8026	1.0	101	nd	11.2	244	Qmf1	0.0	364	Qmf2	0.0	0	
Woodburn-Hubbard	Wood01	45.1451	-122.8228	6.1	247	Qmf1	33.5	341	Qmf2	0.0	396	QTaf	0.0	0	
Woodburn-Hubbard	Wood02	45.1350	-122.8695	6.7	230	Qmf1	0.0	366	Qmf2	0.0	415	QTaf	0.0	0	
Woodburn-Hubbard	Wood03	45.1538	-122.8499	4.5	211	Qmf1	0.0	303	Qmf2	0.0	0		0.0	0	
Sandy	Sandy01	45.4029	-122.2745	4.5	286	Tbs	0.0	610	Tbs	0.0	0		0.0	0	
Florence-Dunes City	Floren01	43.9920	-124.1062	11.2	218	Qs	0.0	313	Qs	0.0	0		0.0	0	
Florence-Dunes City	Floren02	43.9714	-124.1008	4.4	241	Qs	0.0	371	Qs	0.0	0		0.0	0	
Florence-Dunes City	DuneC01	43.9266	-124.0989	4.0	174	Qs	0.0	576	Tbs	0.0	0		0.0	0	
Grants Pass	Grandp01	42.4578	-123.3286	2.4	257	Qac	0.0	506	grus	0.0	0		0.0	0	
Grants Pass	Grandp02	42.4458	-123.3135	1.5	134	Qaf	7.0	371	Qac	0.0	925	grus	0.0	0	
Grants Pass	Grandp03	42.4244	-123.3449	0.6	321	nd	2.1	554	Qac	0.0	868	grus	0.0	0	
Lincoln City	Lincohn01	44.9805	-124.0020	4.3	185	Qmt	0.0	958	Tbs	0.0	0		0.0	0	
Lincoln City	Inp1	44.9142	-124.0179	8.0	225	Qs	0.0	0		0.0	0		0.0	0	
Lincoln City	Lincohn02	44.9305	-124.0121	0.0	282	Qs	0.0	0		0.0	0		0.0	0	
Newberg-Dundee	Newb01	45.3123	-122.9494	4.9	220	Qmf1	0.0	513	Tbs	0.0	0		0.0	0	
Newberg-Dundee	Newb02	45.2945	-122.9735	7.9	162	Qmf1	0.0	330	QTaf	0.0	0		0.0	0	
Newport	Newp01	44.6399	-124.0504	1.0	200	Qs	6.7	448	Qmt	0.0	613	Tbs	0.0	0	
Newport	Newp02	44.6156	-124.0608	17.0	324	Qs	0.0	419	Qmt	0.0	0		0.0	0	
Seaside-Cannon Beach	Seas01	45.9786	-123.9289	6.7	274	Qs	0.0	365	Qs	0.0	0		0.0	0	
Seaside-Cannon Beach	Seas02	46.0093	-123.9144	12.2	170	Qs	0.0	262	Qs	0.0	0		0.0	0	
Seaside-Cannon Beach	Seas03	46.0302	-123.9196	15.5	208	Qs	0.0	280	Qs	0.0	0		0.0	0	
Tillamook	Tillam1	45.4629	-123.7993	2.4	335	QTac	0.0	610	Tbs	0.0	0		0.0	0	
Tillamook	Tillam2	45.4356	-123.8423	17.0	82	Qe	0.0	308	QTac	0.0	0		0.0	0	
Tillamook	Tillam3	45.4712	-123.8503	17.4	83	Qe	0.0	250	QTac	0.0	0		0.0	0	

Shear Wave Velocity Data Collection Methodology

This section includes a description of our technique for collecting the Shear-Wave velocity data presented in the preceding table. The table is also available on the accompanying CD-ROM disk as a Microsoft Excel ™ spreadsheet.

SH-wave data is collected using a 12-channel Bison 5000 seismograph with 8-bit instantaneous floating-point and 2048 samples per channel. The data is recorded at a sampling rate between 0.025 and 0.5 ms, depending upon site conditions. The energy source for SH-wave generation is a 1.5 m section of steel I-beam struck by a 4.5-kg sledgehammer horizontally. The geophones used for recording SH-wave data are 30-Hz horizontal component Mark Product geophones. Spacing between the geophones is 3.05 m (10ft). The walkaway method (Hunter et al., 1984), in which a group of 12 in-line geophones remained fixed, and the energy source is "stepped out" through a set of predefined offsets. Depending upon site geological conditions, the offsets of 3.05 (10 ft), 30.5 (100 ft), 61.0 (200 ft), 91.5 (300 ft), 122 (400 ft), and 152.4 m (500 ft) are used. In order to enhance the SH-wave and reduce other phases, 5 ~20 hammer strikes in each site of the steel I-beam are stacked and recorded for each offset.

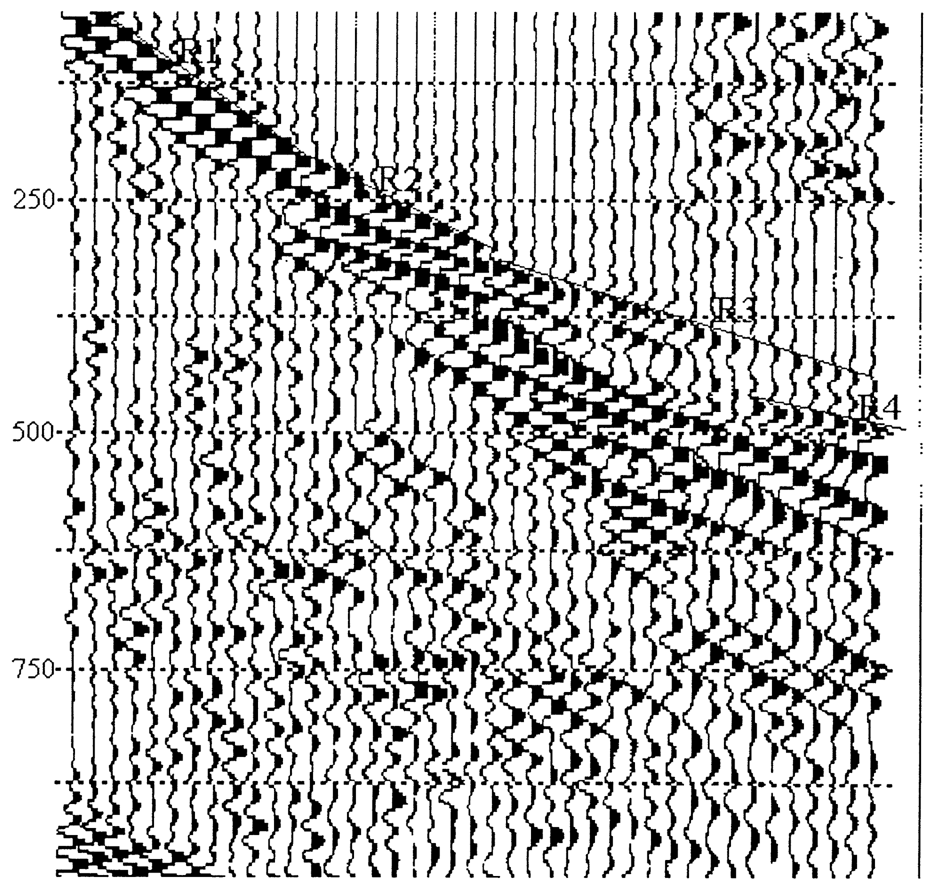


Figure 1. Composited SH-wave refraction profile at site McM03

The SH-wave data are processed on a PC computer using the commercial software SIP (Rimrock Geophysics, Inc., 1995). The key step for data process is to identify the refractions from different horizons. Figure 1 shows the composited SH-wave refraction profile generated from the individual offset records, at site McM03 near Dayton, Oregon. Four refractions, R1, R2, R3, and R4 were identified in the profile. Arrival times of the refractions are picked interactively on the PC using BSIPIK module in SIP. The arrival time data picked from each offset record are edited and combined to generate a data file for velocity model deduction using SIPIN module. Figure 3 shows the arrival times for the refractions identified in the profile (Figure 2). The shear-wave velocity model is generated automatically using SIPT2 module. Figure 4 shows shear-wave velocity model derived from the refraction data at site McM03 (Figure 3).

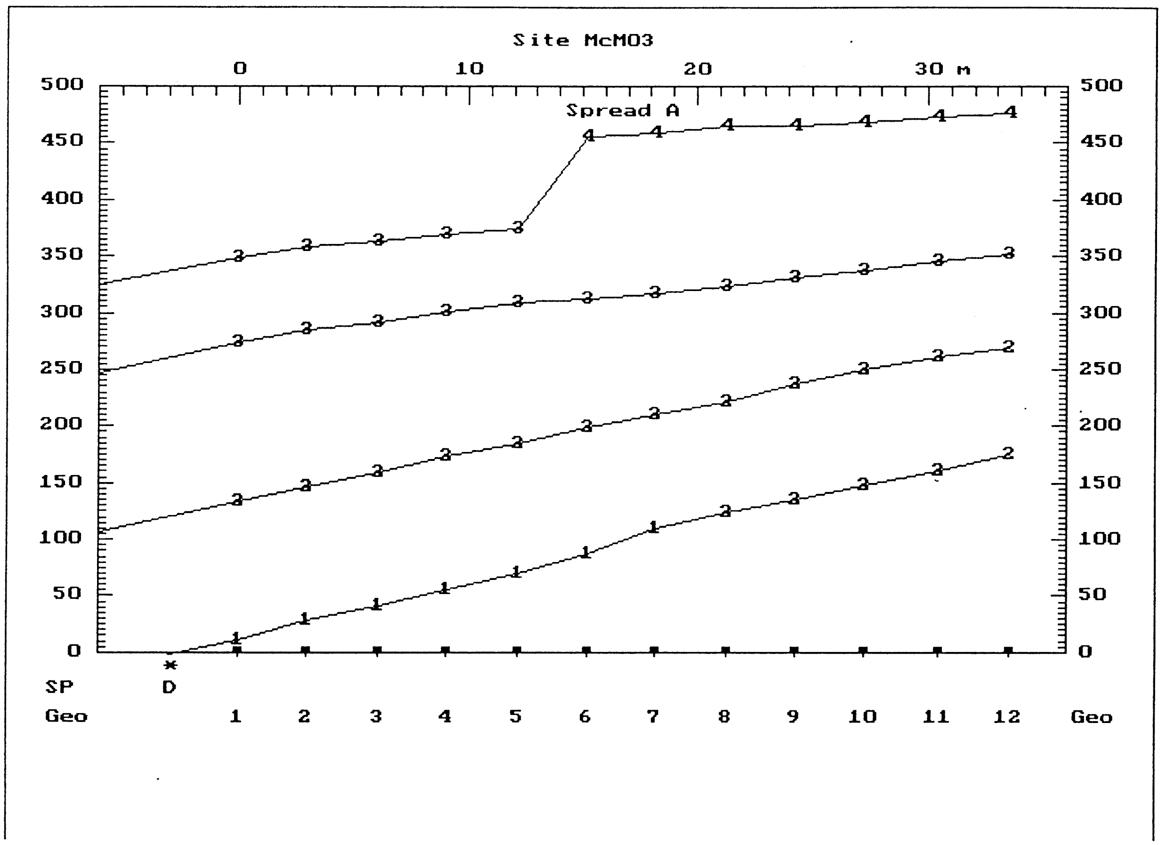


Figure 2. Arrival time curves of the refractions at site McM03.

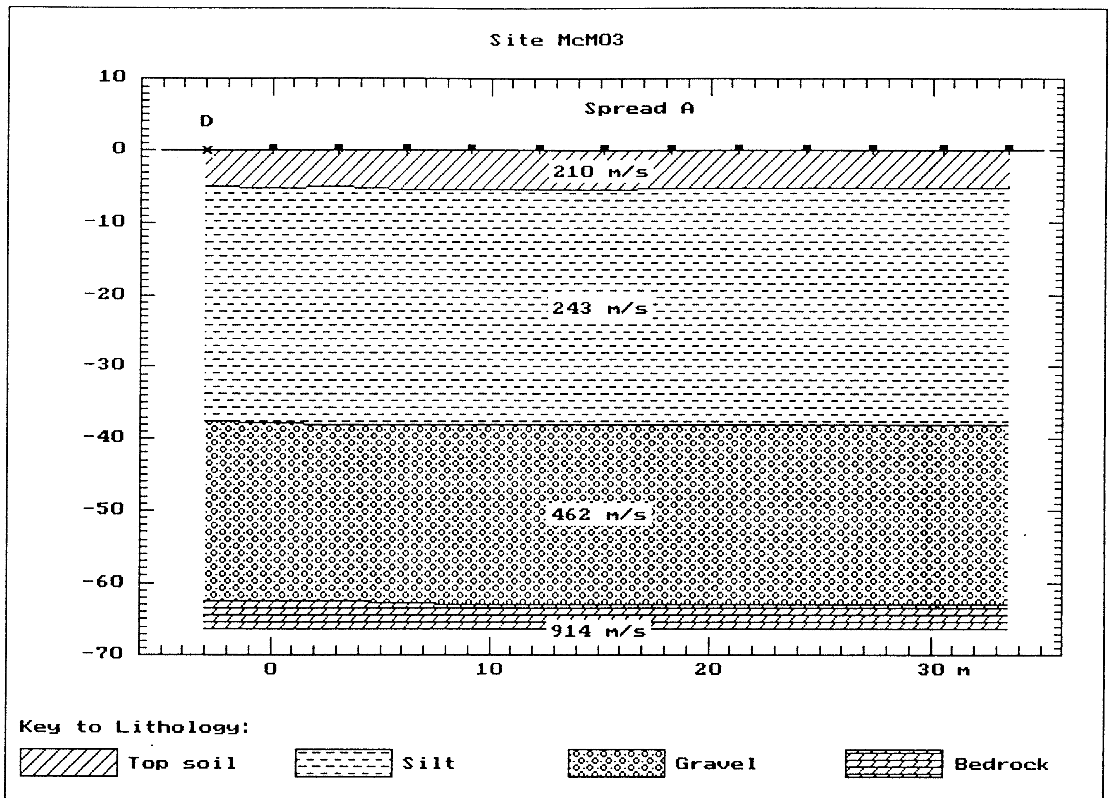


Figure 3. Shear-wave velocity model interpreted from refraction data at site McM03.

UBC-97 Soil Classification

The average shear-wave velocity (v_s) over the upper 30 m of the soil profile is calculated using (ICBO, 1997)

$v_s = 30m/\Sigma\{d_i/v_{si}\}$

Where: d_i = thickness of layer *i* in meters.

v_{si} = shear-wave velocity of layer *i* in m/s.

The UBC-97 soil classification map is generated using MapInfo® and Vertical Mapper®, based on the average shear-wave velocity and Table 1 (ICBO, 1997). Soil types S_E and S_F can not be differentiated from the average shear-wave velocity. S_E and S_F are differentiated based on geologic and geotechnical data, and engineering judgement.

URBAN AREA SUMMARIES

Ashland Urban Area

The Ashland geologic model was developed using recently completed 1:24,000 scale geologic mapping by Dr. Jad D'Alllura of Southern Oregon University. Subsurface geology was interpreted from 77 approximately-located water wells. The geology consists of a thin, irregular body of varied Quaternary alluvial clay, sand and gravel (Qac) deposited on an irregular surface of Jurassic through Eocene bedrock (KJg).

The geologic model consists of a single body of Quaternary alluvium.

Shear wave velocity is assigned as follows:

Qaf two direct measurements 194-327 m/sec, average 260 m/sec

KJg two direct measurements, weathered zone 7-13m thick is 640-770 m/sec (average 680 m/sec) and unweathered rock is 1015-1220 m/sec average 1117 m/sec.

The relatively thin and high-velocity alluvium has low amplification hazard, the bedrock areas have none.

The Quaternary alluvium is typically clayey or gravelly, and is likely to have very low liquefaction susceptibility.

The steeper slopes in the western part of the area are underlain by Jurassic granite, and are unlikely to be very susceptible to landslides, except perhaps where there is thick grus (a layer of decomposed granite). The more moderate slopes along the eastern edge of the area consist of Eocene rocks overlying Cretaceous metamorphic rocks. One large slide occurs along this contact in the northeast edge of the area.

The majority of the area is in Relative hazard Category A, reflecting low amplification, no liquefaction and low landslide hazard. Small areas of higher hazard category are associated largely with steep slopes and existing landslides.

Brookings Urban Area

The geologic model for the Brookings area was developed using surface geologic data at 1:62,500 from Beaulieu and Hughes (1976), unpublished 1:24,000 scale mapping of marine terraces by Dr. Harvey Kelsey of Humboldt State University and subsurface data from 64 approximately-located water and geotechnical wells. The geology consists of Quaternary Marine terrace sand, silt and clay (Qmt) deposited over Jurassic melange bedrock (KJm). Quaternary sand and gravel alluvium (Qac) fills the channel of the Chetco River.

The model consists of a body of marine terrace sediments over bedrock and a body of Quaternary Alluvium over terrace sediments.

Shear wave velocities are assigned to the units as follows:

Qac no direct measurements, Qac at other similar sites averages 223 m/sec

Qmt one direct measurement, 481 m/sec

KJm one direct measurement at 1172 m/sec.

Amplification is nil in most of the area, with the exception of the floodplain of the Chetco river, where it is high.

Liquefaction is probably a minimal hazard in most of the area because the terrace sediments are high-velocity and fairly weathered (drillers report many hard or cemented horizons). Liquefaction hazards are restricted to the Quaternary Alluvium along the Chetco River.

Although slopes are steep, there are no obvious prehistoric landslides, and no mapped slides, possibly because the bedrock is very competent. Earthquake-induced landslide hazards are restricted to the steepest slopes.

The majority of the area is in Relative hazard Category A, reflecting low or no hazard in most categories. The exceptions are some of the steepest slopes and the alluvium along the Chetco River.

COQUILLE URBAN AREA

The geologic model for the Coquille area was developed using 1:62,500 scale surface geologic data from Beaulieu and Hughes (1975) and subsurface geologic data from 24 approximately located water wells. The geology consists of Pleistocene and Holocene alluvial silt and clay (Qaf) deposited on Eocene sedimentary bedrock (Tbs). The model consists of a single body of Qaf over bedrock.

Shear wave velocities were assigned as follows:

Qaf Two direct measurements, 151 and 191 m/sec, average 171 m/sec.
Tbs Two direct measurements, 385 and 589 m/sec, average 487 m/sec.

Amplification is low in the bedrock slopes around Coquille, and moderate to high on the flats adjacent to the Coquille River and its major tributaries.

Liquefaction hazard is moderate to high adjacent to the Coquille River and its major tributaries.

Earthquake-induced landslide hazards are generally low to moderate, with a few areas of high hazard on old landslides or in a few very steep areas I the hills surrounding the urban area.

Most of the flat areas along the Coquille River and its tributaries are in Relative hazard category D and C, reflecting high amplification and liquefaction hazards. The surrounding hills are generally in hazard Category B, with areas of Category C associated with steep slopes and existing landslides.

COTTAGE GROVE URBAN AREA

The geologic model for the Cottage Grove area was developed using published surface geologic mapping (Walker and McLeod, 1991), air photo interpretation and subsurface data from 69 approximately located water wells. The geology consists of Pleistocene and Holocene alluvial sand and gravel (Qac) deposited on Eocene-Miocene sedimentary and basalt sedimentary bedrock (Tbs). The model consists of a single body of Qac over bedrock.

Shear wave velocities were assigned as follows:

Qac Two direct measurements, 187 and 219 m/sec, average 203 m/sec.
Tbs Two direct measurements, 973 and 1270m/sec, average 1121 m/sec.

Amplification is low to moderate in the bedrock slopes adjacent to the floodplains of the Coast Fork Willamette and Row Rivers, and moderate in the floodplains where the alluvium is fairly thick.

Liquefaction hazard is nil.

Earthquake-induced landslide hazards are generally low on the floodplains of the Coast Fork Willamette and Row rivers, and moderate on the adjacent slopes, high landslide hazard is restricted largely to areas of existing landslides.

Most of the area is in relative hazard Category A, with a large area of Category B along the valley floor, and some areas of category C in the hills associated with existing landslides.

Florence-Dunes City Urban Area

The Florence-Dunes City Geologic Model was developed using surface geology from Schlicker and others (1974) and subsurface data from 69 approximately-located water wells. The geology of the area consists of Holocene beach dune sands (Qs) on top of sedimentary bedrock of the Eocene Tyee formation (Tbs). The geologic model consists of a body of Qs over bedrock.

Shear wave velocities are assigned as follows:

Qs Five direct measurements, ranging from 174 to 371 m/sec, average 263 m/sec.

Tbs One direct measurement, 576 m/sec.

Amplification is low in the bedrock areas of the urban area, and moderate in the flatter areas underlain by Qs.
Liquefaction is likely to be a widespread hazard is Qs, given the abundance of young clean dune sands and a relatively shallow water table.
Earthquake-induced landslide hazards are generally low, with some areas moderate on the steepest slopes.
Most of the coastal plain is in Relative hazard Category D, reflecting a combination of liquefaction and amplification hazards. Inland, the hilly areas are generally Category B, reflecting moderate slope hazards and low amplification.

Grants Pass Geologic Model

The Grants Pass geologic model was developed using surface geologic data from Walker and McLeod (1991), Ramp and Peterson (1979) and air photo interpretation. Subsurface data was interpreted from 224 approximately-located water wells.

The geology consists of Quaternary alluvial gravel and sand (Qac) filling the valley of the Rogue River The gravel overlies granite and metamorphic bedrock, the granite is typically covered by a blanket of decomposed material (grus) up to tens of meters thick. The geologic model consists of a body of gravel, a body of grus, and bedrock (Kjg).

Shear Wave Velocity was assigned as follows:

Qac Three direct measurements, from 371 to 554 m/sec, average 477 m/sec.
grus Two direct measurements, 868 and 925 m/sec, average 896 m/sec.

Amplification is low to nil, because the Qac alluvium is relatively high-velocity.
Liquefaction is nil, because the Qac is dense and gravelly.
Earthquake-induced landslide hazards are mostly low, with some moderate hazard in the hills adjacent to the Rogue River valley floor, and a few small areas of high hazards associated with the steepest slopes in the hills.
Most of the area is in Relative hazard category A, with a few spots of higher hazard associated with the steepest slopes.

REEDSPORT-WINCHESTER BAY URBAN AREA

The Reedsport-Winchester Bay geologic model was developed using surface geologic mapping at 1:62,500 (Beaulieu and Hughes, 1975) air photo interpretation and subsurface data from 30 approximately-located water wells. The geology consists of Pleistocene (Pe) and Holocene (Qe) estuarine and alluvial sand, silt and clay deposited by the Umpqua River over Eocene sedimentary bedrock (Tbs). The Pleistocene and Holocene deposits occupy the present channel and floodplain of the Umpqua River, and at Reedsport, the Pleistocene deposits fill an abandoned meander of the Umpqua River. The geologic model consists of a body of Holocene fine-grained alluvium, a body of Pleistocene sand and gravel alluvium, and bedrock.
Shear wave velocities are assigned as follows:
Qe One direct measurement, 89m/sec.
Pe Two direct measurements, 144 and 142 m/sec, average 143 m/sec.
Tbs One direct measurement, 749m/sec.

The amplification hazard in the area is generally high, with the exception of areas underlain by bedrock, principally in the hills.
Liquefaction hazard is high in areas of unit Qe, which is predominantly very young and soft sit and sand along the Umpqua River and tributaries. The liquefaction potential is somewhat less I areas underlain by Pe, because it is more consolidated and older. Liquefaction hazard in the hills is nil.
Earthquake induced landslide hazards are generally moderate in the hills, with significant areas of high hazard due to steep slopes.
Most of the low-lying flats along the Umpqua River and Winchester Creek are in Relative hazard Category D, reflecting high amplification and liquefaction hazards. Most of the surrounding hills are in Category A, with some areas of higher hazard associated with steep slopes..

ROSEBURG URBAN AREA

The Roseburg geologic model was derived using unpublished digital 1:24,000 scale geologic mapping provided by Dr. Ray Wells of the US Geological Survey and subsurface data from 40 approximately-located water wells. Quaternary alluvial terraces and alluvium (Qac) overlie complex, largely Eocene and older bedrock (Tbv). The geologic model consists of a body of Qac over bedrock. Shear wave velocity was assigned as follows:

Qac One direct measurement, 181 m/sec.
Tbv One direct measurement, 944m/sec.

Amplification hazards are low to nil, since most of the area is either bedrock, or fairly thin alluvium.
Liquefaction hazards are nil because the alluvium is gravelly and thin.
Earthquake-induced landslide hazards are generally low to moderate, with a few small areas of high hazard, mostly associated with existing slides.
Most of the area is in Relative hazard Category A, with some small areas of higher hazard associated with existing landslides and steep slopes.

SUTHERLIN-OAKLAND URBAN AREA

The Sutherlin-Oakland geologic model was derived using digital 1:24,000 scale geologic mapping provided by Dr. Ray Wells of the US Geological Survey and subsurface data from 35 approximately-located water wells. Quaternary alluvial terraces and alluvium (Qaf) overlie complex, largely Eocene and older bedrock (Tbv). The thickness model consists of a body of Qaf up to 5 meters thick over bedrock.
Shear wave velocities were assigned as follows;

Qaf Two direct measurements, 198 and 426 m/sec, average 312 m/sec.
Tbv Two direct measurements, 842 and 1079 m/sec, average 960 m/sec.

Amplification hazards are nil to low, because the area is either bedrock or very thin alluvium.
Liquefaction hazards are nil, because the area is either bedrock or very thin, relatively dense alluvium.
Earthquake-induced landslide hazards are generally low to moderate with a few areas of high hazard associated with existing landslides and very steep slopes.
Most of the area is in Relative hazard Category A, with some small areas of higher hazard associated with existing landslides and steep slopes.

ASTORIA-WARRENTON URBAN AREA

The Astoria-Warrenton geologic model was developed using airphoto interpretation, surface geologic data from Schlicker and others (1972) and subsurface data from 21 approximately-located water wells.

The geology of this area was difficult to model because of the very sparse subsurface data set available. The model was largely derived by assuming that the area has been drowned in Quaternary sediment deposited by the Columbia River and its local tributaries as sea level has risen, and that the bedrock topography beneath the Quaternary sediments looks similar to that above.

Shear wave velocity sites were used to fill in data gaps for the thickness of the estuarine sediments. The model consists of a body of Quaternary sand (Qs) and a body of Quaternary estuarine clay and silt (Qe).
Existing landslides are common in the area, particularly in urban Astoria.
Shear wave velocities are assigned to the units as follows:

Qe Three direct measurements, ranging from 70 to 81 m/sec, average 82 m/sec.
Qs Five direct measurements, ranging from 133 to 210 m/sec, average 173 m/sec
Tbs One direct measurement, 530 m/sec.

Amplification hazard is high on the Clatsop plain and floodplains of the Columbia and tributaries due to thick deposits of Qs and Qe. Amplification hazard is low in the adjacent hills, which are bedrock.
Liquefaction hazard is high on the Clatsop plain and floodplains of the Columbia and tributaries due to thick deposits of Qs and Qe. Liquefaction hazard is nil in the adjacent hills, which are bedrock.
Earthquake-induced landslide hazards are low on the Clatsop plain and floodplains of the Columbia and tributaries. Landslide hazard is generally moderate in the adjacent hills, except for large areas of existing landslide, which have high hazard.
Relative hazard is generally Zone D for the Clatsop plain and floodplains of the Columbia and its tributaries due to high amplification and liquefaction hazard. The adjacent hills are mostly in Zone B and C, due to high to moderate landslide and low amplification hazards.

Dallas Urban Area

The Dallas Geologic Model was developed using surface geologic data from Baldwin (1964), Gannet and Caldwell (In Press) and O'Connor (In Review) and subsurface from logs of 51 approximately-located water wells. The geology consists of Quaternary silt, sand and gravel overlying Miocene sedimentary and volcanic bedrock (Tvb). The Quaternary deposits can be grossly divided into an older sand and gravel alluvial unit (QTac)and a younger unit of flood silt (Qmf) deposited by catastrophic Missoula floods (Bretz and others, 1956; Waitt, 1985). The model consists of a body of QTac and a body of Qmf.
Shear wave velocities were assigned as follows:
Qmf Two direct measurements, 165 and 174 m/sec, average 170 m/sec.
QTac No direct measurement, nearby values for similar sediments range from 275 to 438 m/sec, average 346 m/sec.
Tvb Two direct measurements, 755 and 780 m/sec, average 768m/sec.

Amplification hazards are generally low, with a small area of moderate hazard at the east end of the urban area where there is a significant combined thickness of Qmf and QTac.
Liquefaction hazards are nil throughout most of the urban area, and low to moderate to the east in areas underlain by Qmf.
Earthquake-induced landslide hazards are generally low on the valley floors, with some areas of moderate hazard on steeper slopes in the hills.
Relative hazard is generally Category A or B for most of the area, reflecting geology that is largely bedrock or thin QTac gravel. There is a small area of Category C at the east end of the urban area, where moderately thick Qmf and QTac deposits and cause elevated amplification and liquefaction hazards.

Lincoln City Urban Area

The Lincoln City Geologic model was derived from surface geologic data Snavely and others (1976), unpublished detailed mapping by Dr. George Priest of DOGAMI, and Wang and Priest, 1993. Subsurface geology was mapped using data from 38 approximately-located water wells, 4 drill holes or cone penetrometer profiles from Wang and Priest (1995) and 2 Vs refraction profiles conducted for this study.
The geology consists of Quaternary marine terrace deposits (Qmt) and Quaternary alluvial, estuarine and beach deposits (Qs) overlying Tertiary marine sedimentary rocks with some basaltic intrusive rocks (Tbs). The marine terrace sediments consist of one extensive terrace surface, and numerous small patches of uplifted and dissected terrace. The alluvial and estuarine deposits consist of sand, silt and clay filling the ancestral Siletz River valley in what is now Siletz Bay. There is not sufficient data to map the estuarine clays separately from the alluvial sands, but the clays are apparently fairly rare, based on data from Wang and Priest (1995), and are lumped in a singe alluvial unit in this study. Similarly beach deposits could not be readily distinguished from the sand alluvium, but have similar velocities, and so are lumped with the alluvium.
Shear wave velocities are assigned as follows:

Qs	Five direct measurements, 129 to 282 m/sec, average 214.
Qmt	Two direct measurements, 185, 334 m/sec, average 259 m/sec.
Tbs	Two direct measurements, 958 and 626 m/sec, average 792 m/sec.

Amplification hazards are nil in the hilly bedrock areas, low on the terraces between the hills and the beach, and moderate in the middle of Siletz Bay where the Qs is very thick.
Liquefaction hazards are nil in the hilly bedrock areas, low on the flat terraces between the hills and the beach, and moderate to high on the flats surrounding Devils Lake and Siletz Bay.
Earthquake-induced landslide hazards are low on the flats around Siletz Bay and Devils Lake, and on the flat terraces between the hills and the beach. In the hills,

landslide hazards are generally moderate, except for several areas of existing landslides and a few areas of very steep slopes.
The majority of the area is in Relative Hazard Category A, with areas up to Zone C around Devils Lake and up to Zone D in Siletz Bay. There are scattered areas up to Zone C in the hills associated with existing landslides.

McMinnville-Dayton-Lafayette Urban Area

This model was developed using surface geologic from Gannett and Caldwell (In Press), Yeats and others (1991) and Brownfield and Schlicker (1981). Subsurface data was obtained from 165 approximately-located water well logs. The geology consists of three units of Quaternary material deposited on top of bedrock. The bedrock consists of basalt flows of the Columbia River Basalt Group, tuffaceous marine sedimentary rocks of the Oligocene and Eocene Keasey and Pittsburgh Bluff Formations, tuffaceous sedimentary rocks and pillow basalts of the Eocene Nestucca Formation, and Eocene basalt and gabbro sills and dikes (Tbs). The oldest Quaternary unit (QTaf) consists of Pleistocene fluvial sand, silt, clay and gravel, and is overlain by two layers of Quaternary silt deposited by catastrophic outburst floods from glacial Lake Missoula (Bretz and others, 1956; Waitt, 1985). The two units of Missoula flood silts can be distinguished by a consistent color change in drillers logs (upper brown-tan, Qmf1, lower blue-gray Qmf2), and have different shear wave velocity values based on field measurements. The geologic model consists of a body of Qmf1, a body of Qmf2, and a body of QTaf.
Shear wave velocity values are assigned as follows:

Qmf1	Three direct measurements, 180-213 m/sec, average 198 m/sec.
Qmf2	Two direct measurements, 241 and 277 m/sec average 259 m/sec.
QTac	One direct measurement, 460 m/sec.
Tbs	One direct measurement, 1371 m/sec.

Amplification hazard is moderate over most of the area, due to widespread thick deposits of Qmf1 and Qmf2. There are some areas of low to nil hazard in the hills along the north edge of the urban area bedrock is at the surface.
Liquefaction hazard is moderate over most of the area, associated with widespread Qmf1 and Qmf2 deposits. Liquefaction hazard is low in the hills along the north edge of the urban area where bedrock is at the surface.
Earthquake-induced landslide hazards are low throughout the area. Moderate hazards occur in the hills at the west end of the urban area and on steep bluffs along the Yamhill River and its major tributaries.
Most of the area is in relative hazard Category C, with some areas of Category A and B in the hills along the north edge of the urban area. The large area of Category C is due to the combination of moderate amplification and liquefaction hazards in the areas underlain by Qmf1 and Qmf2.

Monmouth-Independence Urban Area

The Monmouth-Independence geologic model was developed using geologic data from Bela (1981), and Gannet and Caldwell (In Press). Subsurface geology was inferred using data from 49 approximately-located water wells. The surface geology was divided into three units, Holocene sand and gravel deposited on the floodplain of the Willamette River (Qac), Late Pleistocene silt (Qmf) deposited by catastrophic floods from lake Missoula (Bretz and others, 1956; Waitt, 1985) and Eocene sandstone and claystone bedrock (Tbs). A unit of Plio-Pleistocene sand and gravel (QTac) was recognized only in the subsurface. The model includes a body of Qac, a body of Qmf and a body of QTac. Qac and Qmf completely cover QTac, which pinches out to the west.

Shear wave velocities are assigned as follows:

Qmf Two direct measurements, 159 and 169 m/sec, average 164 m/sec.
QTac Two direct measurements, 275 and 325 m/sec, average 300 m/sec.
Qac No direct measurements, similar gravel at Lebanon is 144 m/sec.
Tbs Two direct measurements, 403 and 550 m/sec, average 480 m/sec.

Amplification hazards are moderate throughout the area, because of widespread Qmf deposits. There is a small area of low hazard in the hills at the west end of the urban area.

Liquefaction hazards are moderate throughout the area, because of widespread Qmf deposits. There is a small area of low and nil hazard in the hills at the west end of the urban area, and an area of low hazard along the bluff above the Willamette River in the center of the urban area.

Earthquake-induced landslide hazards are generally low throughout the area, with a small area of moderate hazard in the hills at the west end of the urban area, and more moderate hazard areas along the bluff above the Willamette River. A small area of high hazard at the west end of the urban area is due to very steep slopes.

Most of the area is in Relative Hazard Zone C, reflecting the combination of moderate amplification and liquefaction hazard associated with widespread Qmf deposits. The hills at the west end of the urban area are in Zones B and A, since these areas have bedrock at the surface. There is also an area of Zone B beneath the urban centers of Monmouth and Independence, due to lower liquefaction hazard.

Newberg-Dundee Urban Area

The Newberg-Dundee geologic model was developed using surface geologic data from Gannet and Caldwell (In Press) and airphoto interpretation. Subsurface geology was inferred from 151 approximately-located water wells and 2 shear wave velocity profiles.

The geology is complex, particularly in the subsurface. Surficial deposits consist of two layers of Quaternary silt deposited by catastrophic Missoula floods (Bretz and others, 1956; Waitt, 1985), and sand and silt alluvium deposited on the floodplain of the Willamette River. The flood silt can be divided into an upper oxidized low-velocity layer (Qmf1) and a lower unoxidized higher-velocity layer

(Qmf2). The Quaternary alluvium was lumped with the Qws1 unit because of the difficulty of distinguishing the two units in well logs and because their shear wave velocities are likely to be similarly low.
The Quaternary units overlie a complex geology consisting of Plio-Pliestocene sand, silt and clay (QTaf), laterite developed on Columbia River Basalt (lat), Columbia River Basalt (Tbv), and Miocene marine sediments (Tbs). There are almost certainly significant faults in the area, because the thickness of the above units change abruptly at several locations, but mapping these faults was not possible in this study. Numerous well logs reported red and brown clay, silt, siltstone, sandstone and mudstone. These descriptions could conceivably be assigned to the laterite, Plio-Pleistocene sediments or Miocene sediments. The complexity of these units was not possible to resolve in this study. Instead we assumed that the velocity of the QTac and lat units would be similar, and lumped them, and assumed the velocity of the Tbs and Tbv units was also similar and lumped them. The final model consists of a body of Qmf1, a body of Qmf2, a body of QTac, and Tbv.

Shear wave velocity is assigned as follows:

Qmf1 Two direct measurements, 162m/sec and 220 m/sec, average 188m/sec
Qmf2 No direct measurement, values from adjacent McMinnville area (10-20 km away) average 259 m/sec.
QTac One direct measurement, 330 m/sec, comparable to McMinnville (416 m/sec) and Woodburn (20 km away, 303-366 m/sec, average of four values 344m/sec).

Tbv One direct measurement, 513 m/sec.

Amplification hazards are generally moderate in the flat lowland parts of the urban area, which are generally covered with Qmf deposits. In the surrounding hills amplification is generally low.
Liquefaction hazards are generally low in the flat lowland parts of the urban area, which are generally covered with Qmf deposits, but increase to moderate as the Qmf thickens towards the Willamette River. In the surrounding hills liquefaction hazard is nil.
Earthquake-induced landslide hazards are generally low on the flat lowlands, and moderate in the hills and along the valleys cut by minor streams. There are areas of high landslide hazard on the steepest slopes on Chehalem Mountain, and along the bluffs above the Willamette River.
Most of the area is in relative hazard Category B, with areas of C towards the Willamette River, reflecting higher liquefaction hazard associated with thicker Qmf. There are also pockets of Category C and D in the Chehalem Mountains where slopes are very steep, and areas of Category D along the Willamette River bluffs.

NEWPORT URBAN AREA

The Newport Geologic model was developed using unpublished surface geologic data from Dr. George Priest, and data from Ticknor (1993). Subsurface geology was inferred from Ticknor (1993) and from 32 approximately-located water wells. The geology consists of marine terrace sediments of Late Quaternary age (Qmt) and Holocene sand silt and clay alluvium (Qs) over Tertiary mudstone and basalt bedrock (Tbs). The alluvium is restricted to Yaquina Bay and the low elevation bench at South Beach. Existing landslides on the bedrock slopes in the area are common, as are slides along the bluffs above the coastline.
Shear wave velocities are assigned as follows:

Qmt One direct measurement 448 m/sec

Qs We made measurements at one site on Qs, but the values (324 and 419 m/sec) were anomalously high. The measurements were made near the north jetty, and may have been made over artificial fill. Consequently we used the average value for Qs and Qe sediments at the Lincoln City, Tillamook and Astoria-Warrenton sites (148 m/sec, average of 12 values).

Tbs one direct measurement, 613 m/sec.

Amplification hazards are low throughout most of the area, reflecting relatively high-velocity Qmt deposits on the terraces and Tbs in the hills. Amplification hazards are generally high in Yaquina Bay, reflecting thick Qs.
Liquefaction hazards are low on the flat terraces between the hills and the coast, reflecting Qmt deposits. Liquefaction hazard in the bedrock hills is nil. Liquefaction hazard in Yaquina Bay is moderate to high, due to thick Qs deposits.
Earthquake-induced landslide hazards are low on the flat terrace surfaces and in Yaquina Bay, moderate on most of the hills surrounding the area, and high in areas of existing landslides, both in the hills and along the coastal bluffs.
Much of the area on the flat terraces is in Relative hazard category A and most of the hilly areas are in Category B, reflecting moderate slope hazard. Areas of Category C are common in the hills and along the coastal bluffs, associated with existing landslides. Yaquina Bay and the surrounding flats are in Category D, reflecting high liquefaction and amplification hazards.

SEASIDE-GEARHART-CANNON BEACH URBAN AREA

The Seaside-Gearhart-Cannon Beach geologic model was developed using surface geology from Schlicker and others (1972) and subsurface data from 21 approximately-located water wells. The geology of the area consists of Holocene dune and beach sand (Qs) deposits on top of Miocene volcanic and sedimentary bedrock (Tbs). Large ancient landslides are abundant on the bedrock slopes. Only one well actually penetrated the entire Qs section, so the thickness model is based on the assumption that the bedrock topography beneath the Qs deposits is similar to that exposed above. The geologic model consists of a body of Quaternary dune and beach sands over bedrock. However, Dr. Curt Peterson (Personal Communication, 1998) indicates that the Quaternary section is quite variable, including buried Holocene gravel bars and beach sand facies of different density and an underlying layer of denser Pleistocene sands. These varied deposits are reflected in the wide range of measured shear wave velocities, but cannot be mapped with the data available. Therefore the Quaternary deposits are treated as a single body, and the measured velocities are averaged.

Shear wave velocities are assigned as follows:

Qs Six direct measurements, ranging from 170 to 365 m/sec, average 260m/sec.

Tbs no direct measurements, similar rocks to the north at Astoria have velocities of 530m/sec, and at Tillamook, 610 m/SEC. The average used for this site is 570 m/sec.

Amplification hazard throughout most of the area is low, reflecting the bedrock that underlies most of the hilly areas. Amplification hazards on the Seaside-Gearhart coastal plain and the lowland flats at Cannon Beach are moderate, reflecting thick Qs deposits.

Liquefaction hazard is nil in the hilly reflecting bedrock at the surface. Liquefaction hazards on the Seaside-Gearhart coastal plain and the lowland flats at Cannon Beach are high, reflecting thick Qs deposits

Earthquake-induced landslide hazards are low on the Seaside-Gearhart coastal plain and the lowland flats at Cannon Beach, and moderate to high in the surrounding hills. High values are generally associated with existing landslides.

Most of the Coastal Plain at Seaside-Gearhart, and the lowland flats at Cannon Beach are in Relative hazard Category D, reflecting the combination of moderate amplification hazard and high liquefaction hazard. Most of the surrounding hills are in Category B, with large areas of Category C associated with existing landslides.

SHERIDAN-WILLAMINA URBAN AREA

The geologic model was developed using surface geologic data from Brownfield (1982), Gannet and Caldwell (In Press) and air photo interpretation. Subsurface geology was interpreted from 39 approximately-located water wells and 2 shear wave velocity profiles.

The geology consists of up to 7 m of Quaternary silt and sand (Qmf) including modern stream deposits and material deposited by catastrophic Missoula floods (Bretz and others, 1956; Waitt, 1985). The Qmf fills a shallow valley cut shale and siltstone of the Eocene Nestucca and Yamhill formations (Tbs). There are a few ancient landslides in the hills along the northern edge of the area.

Shear wave velocity is assigned as follows:

Qmf Two direct measurements, 124 and 125 m/sec.

Tbs Two direct measurements 749 and 773 m/sec, average 761 m/sec

Amplification hazards are nil throughout most of the area, with a small strip of low hazard where the Qmf sediments are thickest along the South Fork of the Yamhill River.

Liquefaction hazards are low along the valley floor, due to thin Qmf, and nil in the surrounding hills where bedrock is at the surface.

Earthquake-induced landslide hazards are low on the valley floor, and moderate in the surrounding hills. A few areas of high hazard in the hills are associated with existing landslides.
Most of the area is in Relative hazard Category A, with a few patches of hazard up to Category C associated with existing landslides.

TILLAMOOK URBAN AREA

The Tillamook geologic model was developed using digital geologic data provided by Dr. Ray Wells of the USGS and the subsurface geology was inferred from 48 approximately-located water wells.
The geology in Tillamook consists of Holocene Estuarine silt, clay and peat (Qe) overlying Quaternary fluvial sand and gravel (QTac) over Miocene bedrock (Tbs). The bedrock is not exposed anywhere in the target area. The geologic model consists of a body of Qe and a body of QTac.
Shear wave velocities are assigned as follows:

Qe	Two direct measurements, 82 and 83 m/sec.
QTac	Three direct measurements, 250-335 m/sec, average 297 m/sec.
Tbs	One direct measurement, 610 m/sec.

Amplification hazards are high in much of the area, due to thick deposits of Qe. There is a large area of moderate amplification hazard at the east end of the area, where Qe is relatively thin. Small area of low hazard at the east and northwest edges of the area are associated with bedrock exposed in the hills.

Liquefaction hazards are generally high in the area, with an area of moderate hazard in the east, where the Qe is thin, and small amounts of low to nil hazard in the hills.
Earthquake-induced landslide hazards are low throughout the area, reflecting generally low slopes.
Most of the Area is in relative hazard Category D, due to the combination of liquefaction and amplification hazards associated with Qe. The hazard is less in the east, with moderate sized areas of Category C, B, and A located in the hills and in areas of thin Qe.

CANBY-AURORA URBAN AREA

The Canby-Aurora geologic model was developed using surface geologic data from Gannett and Caldwell (In Press) and O'Connor (), examination of air photos and subsurface data from 112 approximately-located water well records. The geology of the area is relatively complex with two units of Quaternary sediments overlying bedrock. A major Northwest-trending fault traverses the northeast portion of the target area, with vertical separation of the top of the basalt of at least 500 feet, down to the southeast. Northeast of this fault, bedrock consists of basalt flows of the Columbia River Basalt Group (Tbv), southwest of the fault, the basalt is overlain by several hundred feet of Plio-Pleistocene fluvial silt- and sandstone (QTaf). The Quaternary sediments consist of silt, sand and gravel deposited by southward flowing catastrophic floodwater associated with drainage of Glacial Lake Missoula (Bretz and others, 1956; Waitt, 1985) flowing south through the area. The floodwaters scoured an irregular surface on the bedrock units, then deposited an irregular body of pebble to boulder gravel (Qmc) on the scoured surface. The gravel is overlain by sand and silt deposited by waning floodwaters (Qmf). The Willamette and Mollala rivers have incised into the flood deposits, and have deposited small amounts of fluvial sediment on their floodplains. These sediments cannot be differentiated from the underlying flood sediments, and are lumped with the older material.

The geologic model consists of four bodies, one each of coarse and fine flood sediments (Qmc, Qmf) and one each of the bedrock units (Tbv, QTaf).

Shear wave velocities are assigned as follows:

Qmf two direct measurements, 160 and 266 m/sec, average 213 m/sec.

Qmc two direct measurements 657 and 680 m/sec, average 668 m/sec

QTaf no direct measurements. Sediments similar to QTaf at Newberg, McMinnville and Woodburn have a velocity ranging from 328 to 518 m/sec, with an average of 413 m/sec.

Tbv no direct measurements available, average at St Helens area is 957 m/sec

Amplification hazards range from none in the northeast corner of the area (due to bedrock at or near the surface) to moderate in the north and southwest parts of the area (due to thick Qmf deposits). Amplification is low in much of the center of the area due to where the Qmf deposits are thin or absent.

Liquefaction hazard ranges from nil in the northeast and central parts of the area (over Qmc gravel and bedrock) to moderate in the southwest and north parts of the area where there is thick Qmf.

Earthquake-induced landslide hazards are generally low, with the exception of areas of high to moderate hazard associated with bluffs along the rivers in the area and their major tributaries.

Relative hazard Categories vary considerably, with large areas of Category C in the southwest and north ends of the area, associated with Qmf deposits. Small areas of Category D are the result of a combination of high landslide hazard along bluffs with amplification and liquefaction hazard. In the center of the area, there are large patches Category A and B, where the Qmf deposits are thin or absent.

Hood River Urban Area

The Hood River geologic model was derived from surface mapping at 1:62,500 from Beaulieu (1977), from air photo interpretation and subsurface data from 26 approximately-located water wells. The geology consists of several deposits of Quaternary sediments on top of bedrock (Tbv) that includes Miocene Columbia River Basalt and Plio-Pleistocene lava flows and debris flows derived from the Mt. Hood volcano. There are two units of Quaternary deposits. Sand silt and clay deposits along the shores of the Columbia River, and a body of clay on the broad flat in the middle of the area are mapped as unit Qaf. Gravel deposits at the south end of the area are mapped as QTac

Shear wave velocities are assigned as follows:

QTac	Two direct measurements, 271 and 377 m/sec, average 324 m/sec.
Qaf	One direct measurement, 145 m/sec.
Tbv	Two direct measurements, 995 and 1352 m/sec, average 1173 m/sec.

Amplification hazards range from nil to moderate, with the higher values associated with the deposits of Qaf along the Columbia River shore and in the center of the area.
Liquefaction hazards are nil throughout most of the area, where bedrock or unit QTac are at the surface. Moderate liquefaction is associated with unit Qaf in the middle of the area, and high liquefaction hazard associated with Qaf along the Columbia River shore.
Earthquake-induced landslide hazards are generally low, with some areas of moderate hazard associated with bluffs along the Columbia and Hood Rivers, and minor tributaries. Small areas of high hazard are associated with the steepest bluffs and some existing landslides.
Much of the area is in Relative hazard Category A, because there is bedrock at the surface In many area. There are also large patches of Category D associated with the Qaf deposits in the center of the area and along the Columbia shore. Small areas of Category C and D are also associated with existing landslides and steep slopes.

Lebanon Urban Area

The Lebanon geologic model was developed using surface geologic data from Yeats and others (1991), Gannet and Caldwell, (In Press) and O'Connor (In Review) and subsurface data from 91 approximately-located water wells. Landslides were mapped using air photo interpretation.
The geology consists of Quaternary river gravel (Qac) deposited on the floodplain of the Santiam River, and older river gravel, sand and silt (QTac) deposited by the ancestral Santiam River over Tertiary volcanic and volcaniclastic bedrock (Tbv).
Shear wave velocity is assigned to the units as follows:

Qac	One direct measurement 144 m/sec.
QTac	One direct measurement 244 m/sec
Tvb	Two direct measurements, 598 and 665 m/sec, average 631 m/sec.

Amplification hazards range from low to moderate, with moderate values associated with Qac and QTac gravel deposits on the valley floor, and low values associated with the Tbv bedrock in the surrounding hills.
Liquefaction hazards are nil, because the area is entirely gravel or bedrock.

Earthquake-induced landslide hazards range from low on the valley floors to mostly moderate in the surrounding hills. Some areas of high slope hazard in the hills are associated with existing landslides and the very steepest slopes.
Most of the valley floor is in Relative hazard Category B, and most of the surrounding hills are in Category A. Some areas of the hills are in Category B or C, associated with steep slopes or existing landslides.

SANDY URBAN AREA

The Sandy geologic model was developed using geologic mapping (Trimble, 1963) and air photo analysis. There are no late Quaternary unconsolidated deposits in the target area, and the geology consists almost entirely of Pleistocene to Miocene volcaniclastic sandstone and conglomerate, and fluvial mudstone (Tbs). Several moderate-sized landslides occur along the steep walls of the Sandy River canyon.
Shear wave velocity values are assigned as follows:

Tbv Two direct measurements, 286 and 610 m/sec, average 448 m/sec.

Amplification hazards are low throughout the area, reflecting the absence of loose, young surface deposits.
Liquefaction hazards are nil, because the entire area is underlain by bedrock.
Earthquake-induced landslide hazards are low on the flat uplands covering most of the area, and moderate to high along the steep walls of the Sandy River canyon and its tributary valleys. The highest slope hazards are associated with some very steep slopes and existing landslides along the Sandy River canyon.
Most of the area is in Relative hazard Category A, with some areas of higher hazard associated with steep slopes or existing landslides.

SILVERTON-MT. ANGEL URBAN AREA

The Silverton-Mt. Angel geologic model was developed using surface geologic data from Gannet and Caldwell, (In Press) and O'Connor (In Review), air photo interpretation, and logs from 106 approximately-located water wells. The geology consists of bedrock of Miocene tuffaceous sedimentary rocks and lava flows of the Columbia River Basalt group (Tbv) overlain by Miocene to Pleistocene alluvial silt and sandstone (QTaf), Pliocene to Quaternary fluvial gravel (QTac) and Pleistocene to Holocene silt and sand from glacial outburst floods (Bretz and others, 1956; Waitt, 1985) from Lake Missoula (Qmf). The northwest trending Mt. Angel Fault runs through Mt. Angel, and was the likely source for the 1993 M 5.6 Scotts Mills earthquake. The Mt. Angel fault offsets all the geologic units in the model except possibly Qmf, with a total southeast-side down displacement of at least 100m.
The geologic model consists of a body of QTaf, a body of QTac (including modern alluvial gravel) and a body of Qmf.
Shear wave velocities are assigned as follows:

Qmf two direct measurements, 184 and 196 m/sec, average 190 m/sec.
QTac one direct measurement, 418 m/sec'
QTaf one direct measurement, 938 m/sec
Tbv two direct measurements, 1087 and 1402 m/sec, average 1244 m/sec.

Amplification hazards are nil in the southern part of the region , where bedrock is exposed at the surface in the Waldo Hills and at the bedrock hill (Mt. Angel) just east of Mt. Angel. Hazards are low to moderate in most of the valley floor areas, particularly where Qmf is thick.
Liquefaction hazards are nil in the bedrock areas described above, and high over most of the valley floor due to widespread deposits of Qmf.
Earthquake-induced landslide hazards are low through out most of the valley floor, except for areas of moderate hazard along steeper slopes along minor streams. Hazards are moderate in the hills south of Silverton and at Mt. Angel, with a few areas of high hazard associated with steep slopes along the valley of Silver Creek.
The southern half of the area is generally in Relative hazard Category A, with areas of B and C associated with steep slopes. The northern half of the area is generally in Category C, due to amplification and liquefaction hazards associated with Qmf. Some parts of the northern half are in Category A where Qmf is thin or absent.

STAYTON-SUBLIMITY-AUMSVILLE URBAN AREA

The Stayton-Sublimity-Aumsville geologic model was developed from geologic maps by Yeats and others (1991), Gannet and Caldwell (In Press) and O'Connor (In Review) and subsurface data from 44 approximately-located water well records. The geology of the area consists of Quaternary and Pleistocene river gravel (Qac) filling a valley cut into Miocene volcanic and volcaniclastic bedrock units (Tbv). The geologic model consists of a body of Qac.
Shear wave velocities were assigned as follows:
Qac one direct measurement 142 m/sec
Tbv two direct measurements, 551 and 958 m/sec, average 754 m/sec.

Amplification hazards are moderate on the valley floor, due to thick Qac, and low in the surrounding hills.
Liquefaction hazard is nil throughout the area because Qac is predominantly coarse gravel.
Earthquake-induced landslide hazards are low on the valley floor, and generally moderate in the surrounding hills except for a few areas of high hazard associated with the steepest slopes, particularly bluffs along the Santiam River.
Most of the area is in Relative hazard Category A, with areas of higher hazard associated with steep slopes.

ST. HELENS-COLUMBIA CITY-SCAPPOOSE URBAN AREA

The St. Helens-Columbia City-Scappoose geologic model was developed using airphoto interpretation, and existing geologic mapping from Wilkinson and others (1946).Subsurface geology was inferred from 88 approximately-located water wells. The geology of the area is somewhat complex and difficult to model. Quaternary surficial deposits consists of a fine-grained unit and a coarse grained unit. The fine-grained unit (Qaf) consists of silts and sands deposited by the modern Columbia River and by the latest Pleistocene Missoula floods (Bretz and others, 1956; Waitt, 1985). Thick deposits of clay northwest of Scappoose were included in this unit, but could be older. Also, deposits of red clay and silt over Columbia River Basalt bedrock that are probably laterite were included in the fine unit. The coarse units (Qac) consists of pebble to boulder gravel with variable amounts of sit, sand and clay, and are probably largely gravel deposited by the late Quaternary Missoula floods, but may include some older Plio-Pleistocene gravels. Bedrock (Tbv) includes Columbia River Basalt, Miocene marine sedimentary rocks and Plio-Pliestocene conglomerate and sandstone, all of which are lumped in a single bedrock unit.
Several landslides were inferred from airphotos along the bluffs north and west of St. Helens.

Shear wave velocity is assigned to the various units as follows:

Qaf	Two direct measurements, 88 and 132 m/sec, average 110 m/sec
Qac	Two direct measurements, 710 and 830 m/sec, average 770 m/sec
Tbv	One direct measurement 1204 m/sec.

Amplification hazard is quite varied across the area, ranging from high where unit Qaf is thick (particularly along the Columbia River) to nil in the hills adjacent to the Columbia River plain, with some patches of nil amplification on the plain where Qaf is absent or thin.
Liquefaction hazard is also varied, ranging from high along the Columbia to nil in the hills adjacent to the Columbia River plain.
Earthquake-induced landslide hazards are low on the Columbia River plain, and generally moderate in the adjacent hills, with a few areas of high hazard associated with existing landslides.
Most of the Columbia River plain is in Relative hazard Category C and D, reflecting amplification and liquefaction hazards associated with Qaf. Some areas of the plain are in Category A and B where Qaf is thin or absent. The hills are generally in Category A, with some areas of higher hazard associated with steep slopes.

SWEET HOME URBAN AREA

The Sweet Home geologic model was developed using surface geologic data from Yeats and others (1991), Gannet and Caldwell (In Press) and O'Connor (In Review) and subsurface data from 49 approximately-located water wells. Landslides were mapped using air photo interpretation.

The geology consists of Quaternary fluvial gravel and sand (Qac) filling the valley of the Santiam River. The Qac is deposited on Tertiary volcanic and volcaniclastic bedrock. (Tbv). The model consists of a body of Qac.
Shear wave velocities are assigned as follows:

Qac One direct measurement, 203 m/sec.
Tbv One direct measurement, 855 m/sec.

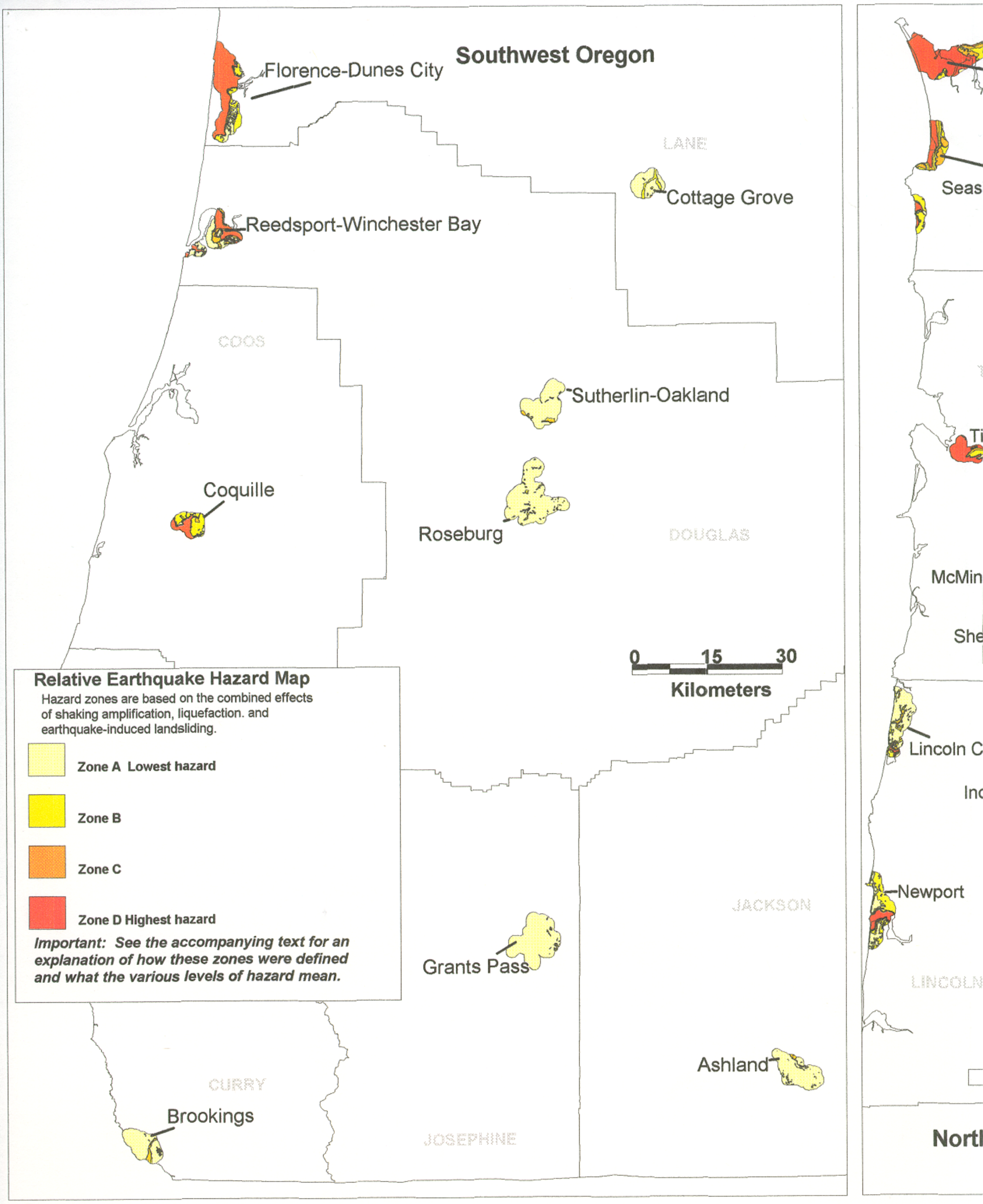
Amplification hazard is low to moderate along the Santiam River valley floor where there is significant thickness of Qac, and nil in the adjacent bedrock hills.
Liquefaction hazard is nil throughout the area, because the Qac is mostly coarse gravel.
Earthquake-induced landslide hazards are low on the valley floor and generally moderate on the adjacent hills. A few areas of high landslide hazard occur in the hills where there are existing slides.
Most of the area is in Relative hazard Category A, with a band of Category B along the Santiam River associated with thick Qac. Some patches of Category C occur in the hills associated with steep slopes and existing landslides.

WOODBURN-HUBBARD URBAN AREA

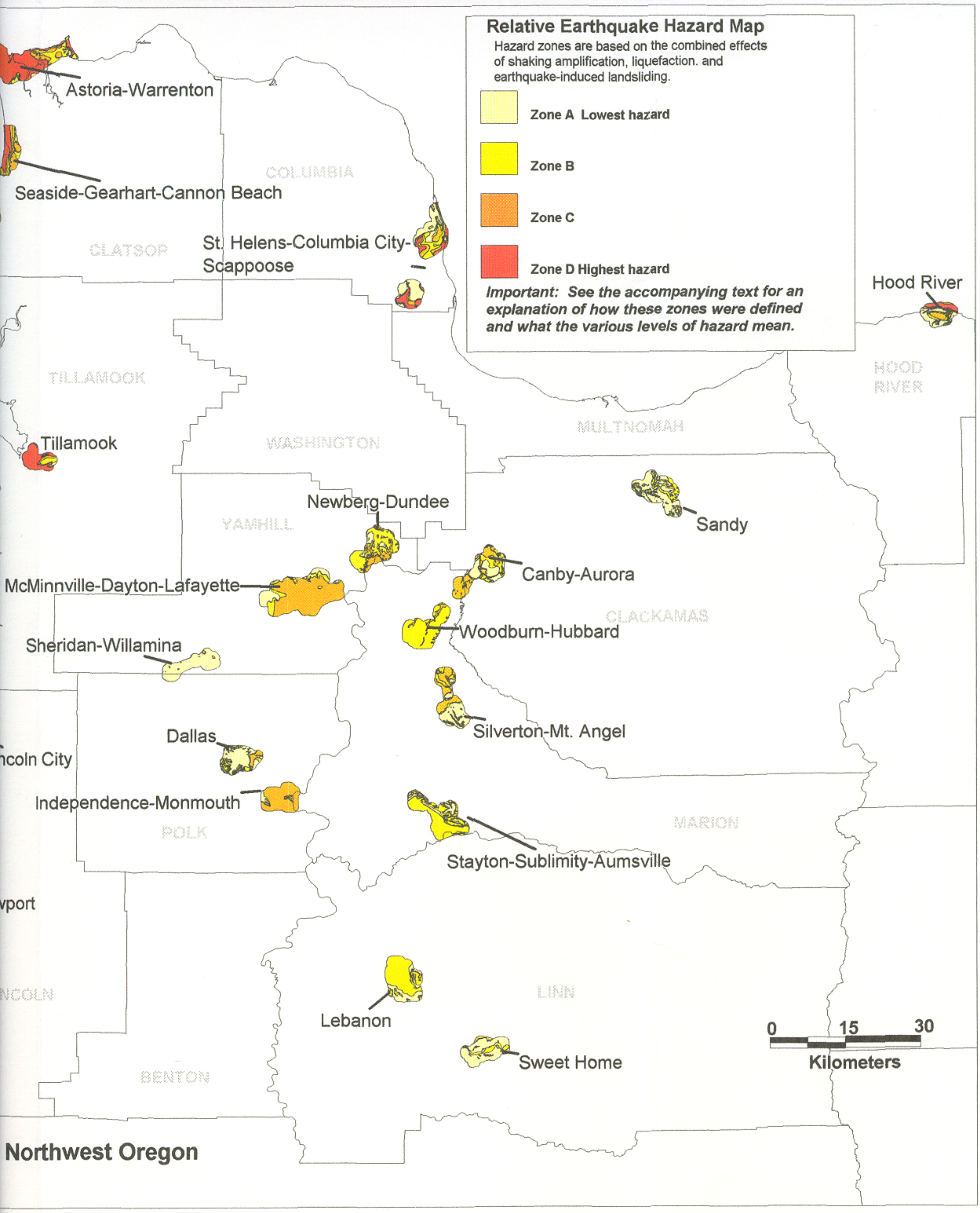
The Woodburn-Hubbard geologic model was developed using surface geologic information from Gannet and Caldwell (In Press), air photo interpretation, and interpretation of logs from 109 approximately-located water wells.
The geology consists of two units of latest Pleistocene silt, deposited by catastrophic Missoula floods (Bretz and others, 1956; Waitt, 1985 on older Pleistocene fluvial, clay, sand and gravel (QTaf). The upper unit of flood silt (Qws1) is brown, the lower unit (Qws2) is blue or gray. The underlying Pleistocene alluvium is composed of clay, sand and gravel. The geologic model consists of a body of Qws1, a body of Qws2 and a body of QTac.
Shear wave velocities are assigned as follows:

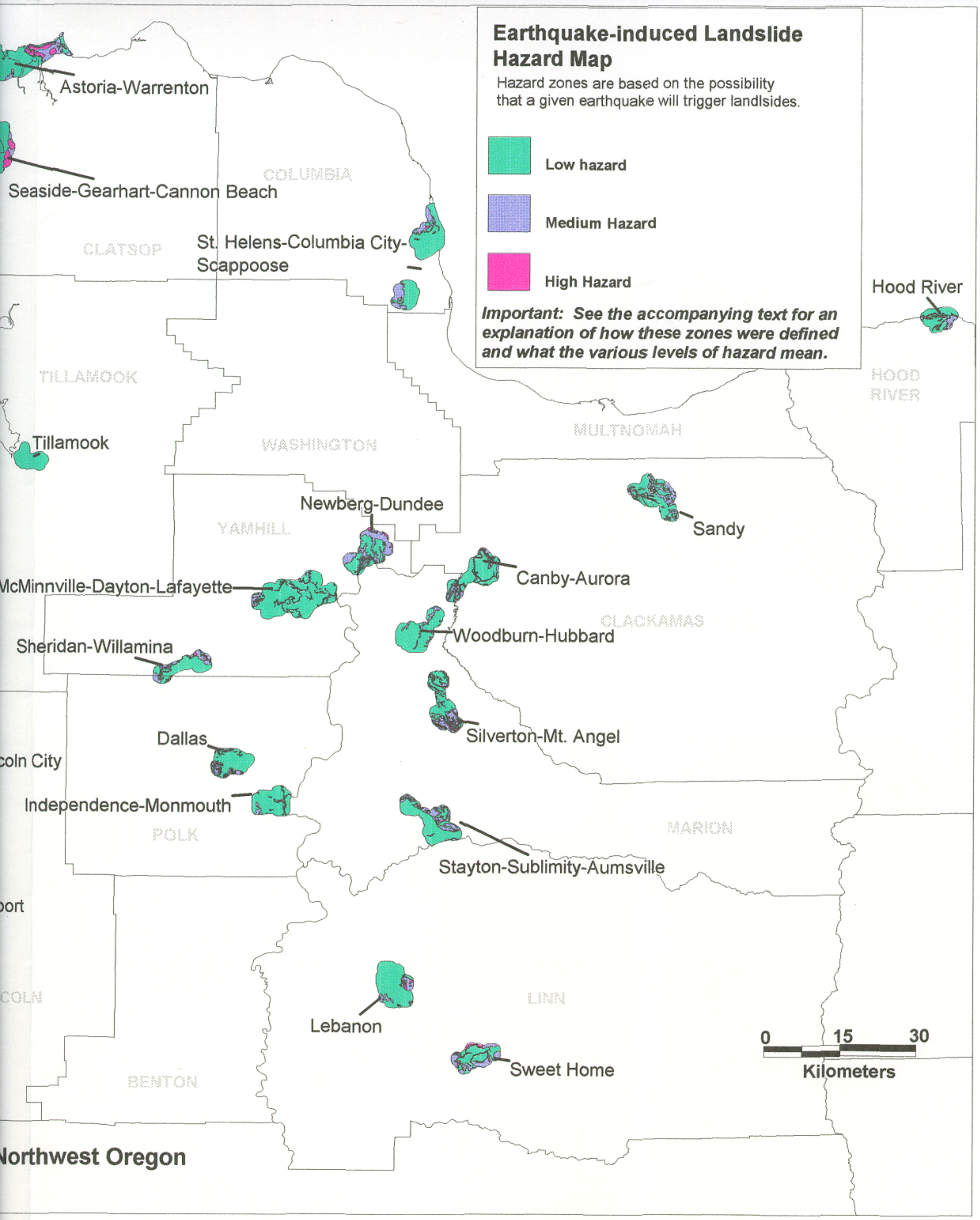
Qws1	Four direct measurements, 211 to 247 m/sec, average 233 m/sec
Qws2	Four direct measurements, 303 to 366 m/sec, average 343 m/sec
QTac	Two direct measurements, 396 to 415 m/sec, average 405 m/sec.

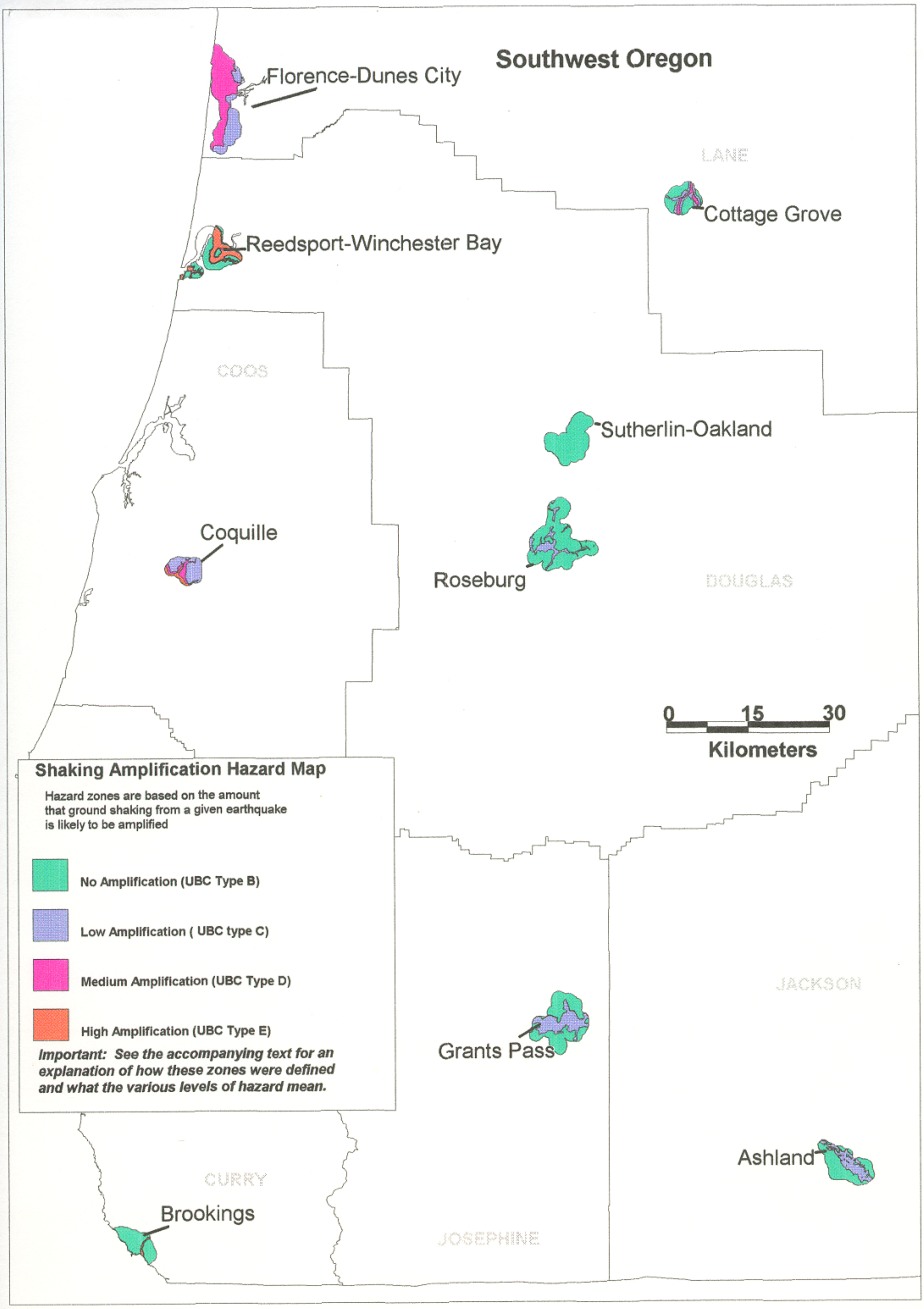
Amplification hazards are moderate throughout the area.
Liquefaction hazards are low throughout the area.
Earthquake-induced landslide hazards are low throughout the area, except for small areas of moderate hazard associated with the walls of small stream valleys.
Most of the area is in Relative hazard Category B, with some areas of Category C associated with steep slopes along minor stream valleys.

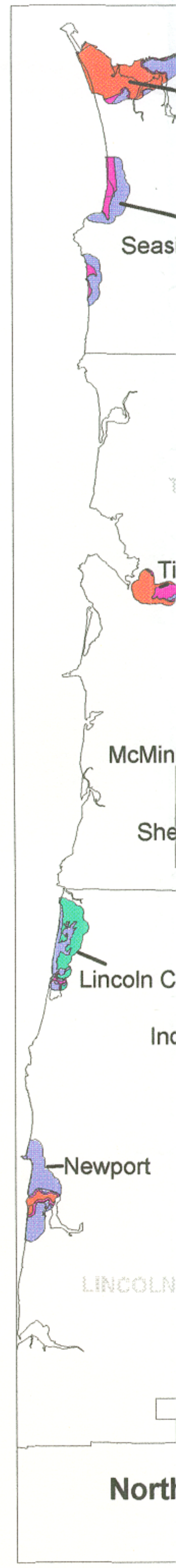


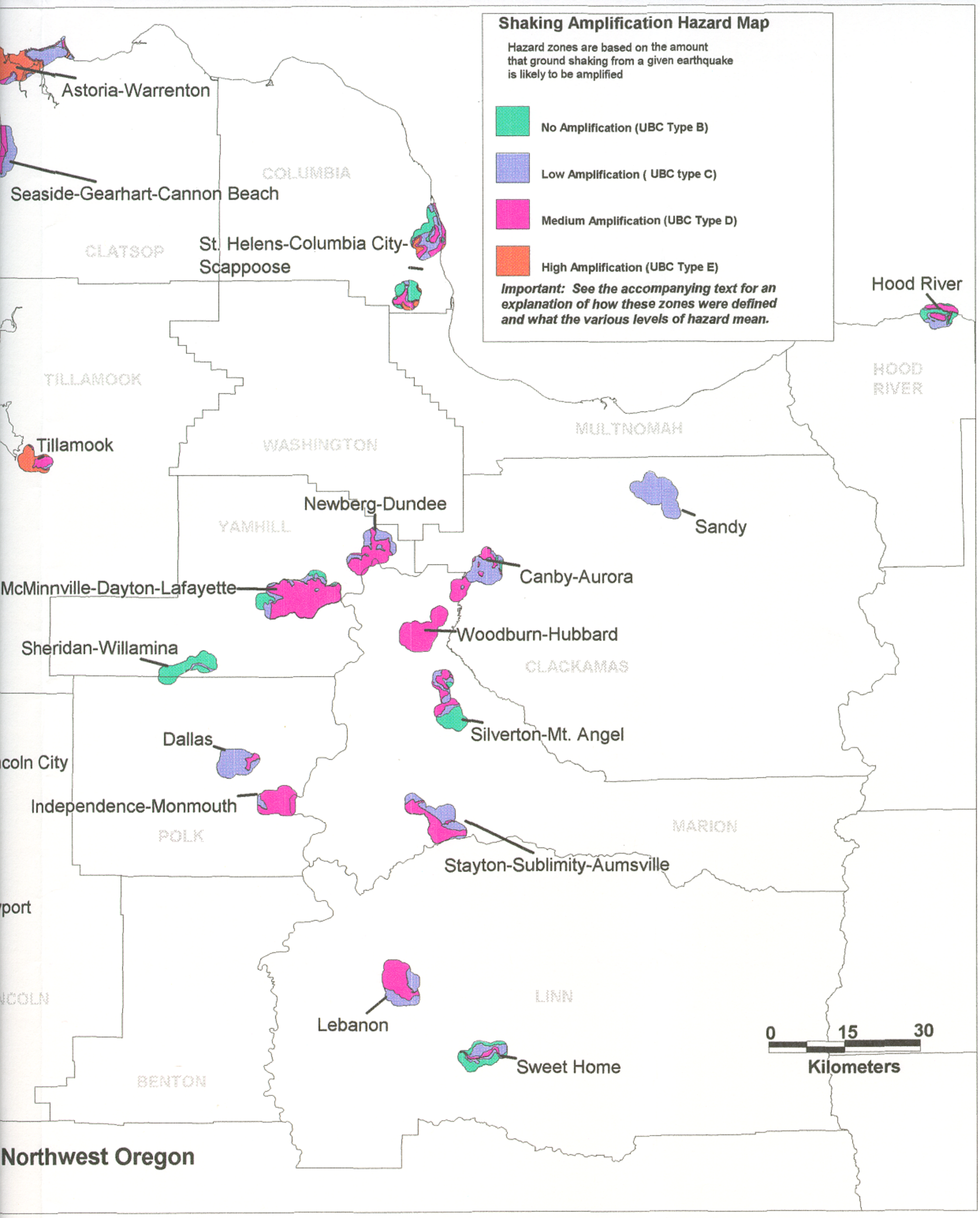
Southwest Oregon
Florence-Dunes City
LANE
Cottage Grove
Reedsport-Winchester Bay
COOS
Sutherlin-Oakland
Coquille
Roseburg
DOUGLAS
0 15 30
Kilometers
Relative Earthquake Hazard Map
Hazard zones are based on the combined effects of shaking amplification, liquefaction. and earthquake-induced landsliding.
Zone A Lowest hazard
Zone B
Zone C
Zone D Highest hazard
Important: See the accompanying text for an explanation of how these zones were defined and what the various levels of hazard mean.
JACKSON
Grants Pass
Ashland
CURRY
Brookings
JOSEPHINE
Newport


Relative Earthquake Hazard Map
Hazard zones are based on the combined effects of shaking amplification, liquefaction. and earthquake-induced landsliding.
Zone A Lowest hazard
Zone B
Zone C
Zone D Highest hazard
Important: See the accompanying text for an explanation of how these zones were defined and what the various levels of hazard mean.
Astoria-Warrenton
Seaside-Gearhart-Cannon Beach
COLUMBIA
CLATSOP
St. Helens-Columbia City-Scappoose
Hood River
HOOD RIVER
TILLAMOOK
MULTNOMAH
Tillamook
WASHINGTON
Newberg-Dundee
YAMHILL
Sandy
Canby-Aurora
McMinnville-Dayton-Lafayette
CLACKAMAS
Woodburn-Hubbard
Sheridan-Willamina
Silverton-Mt. Angel
Dallas
ncoln City
Independence-Monmouth
POLK
MARION
Stayton-Sublimity-Aumsville
wport
NCOLN
LINN
Lebanon
0 15 30
Kilometers
Sweet Home
BENTON
Northwest Oregon

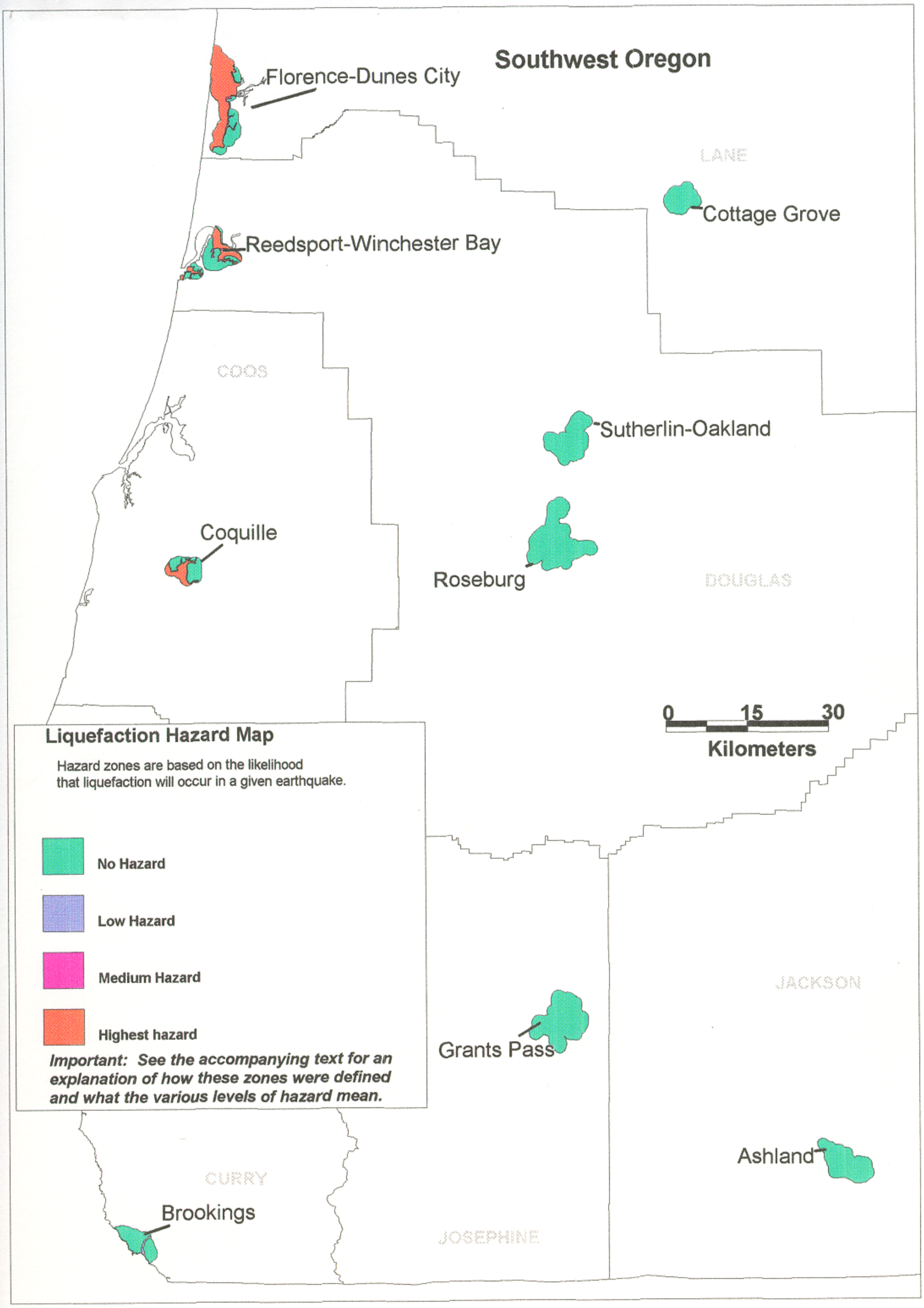

Earthquake-induced Landslide Hazard Map
Hazard zones are based on the possibility that a given earthquake will trigger landlsides.
Low hazard
Medium Hazard
High Hazard
Important: See the accompanying text for an explanation of how these zones were defined and what the various levels of hazard mean.
Astoria-Warrenton
Seaside-Gearhart-Cannon Beach
COLUMBIA
CLATSOP
St. Helens-Columbia City-Scappoose
Hood River
TILLAMOOK
HOOD RIVER
Tillamook
WASHINGTON
MULTNOMAH
Newberg-Dundee
YAMHILL
Sandy
McMinnville-Dayton-Lafayette
Canby-Aurora
CLACKAMAS
Woodburn-Hubbard
Sheridan-Willamina
Silverton-Mt. Angel
Dallas
coln City
Independence-Monmouth
POLK
MARION
Stayton-Sublimity-Aumsville
port
COLN
LINN
Lebanon
0
15
30
Kilometers
Sweet Home
BENTON
Northwest Oregon

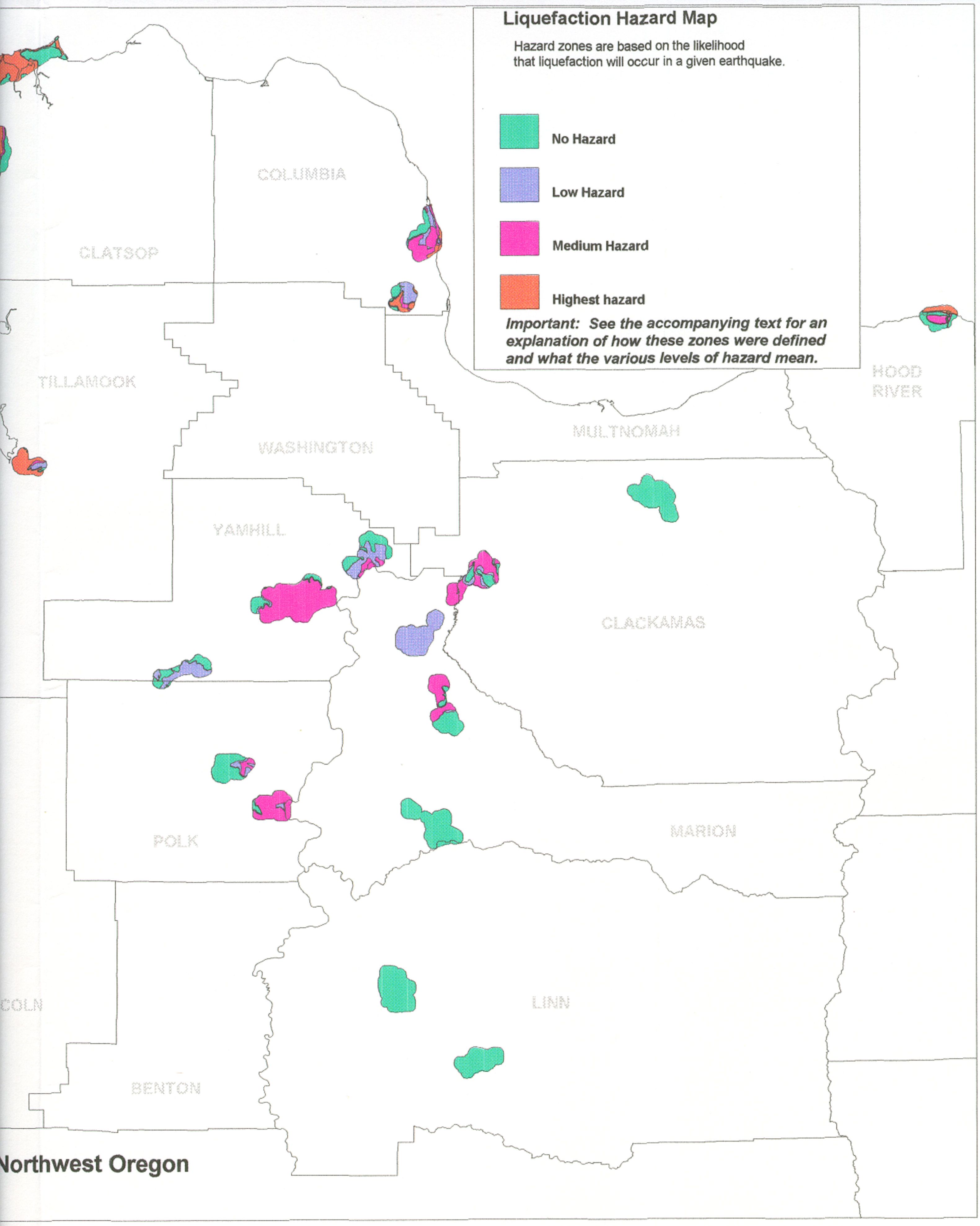

Southwest Oregon
Florence-Dunes City
LANE
Cottage Grove
Reedsport-Winchester Bay
COOS
Sutherlin-Oakland
Coquille
Roseburg
DOUGLAS
0 15 30
Kilometers
Shaking Amplification Hazard Map
Hazard zones are based on the amount
that ground shaking from a given earthquake
is likely to be amplified
No Amplification (UBC Type B)
Low Amplification (UBC type C)
Medium Amplification (UBC Type D)
High Amplification (UBC Type E)
Important: See the accompanying text for an
explanation of how these zones were defined
and what the various levels of hazard mean.
JACKSON
Grants Pass
Ashland
CURRY
Brookings
JOSEPHINE


Newport
LINCOLN



Shaking Amplification Hazard Map
Hazard zones are based on the amount that ground shaking from a given earthquake is likely to be amplified
No Amplification (UBC Type B)
Low Amplification (UBC type C)
Medium Amplification (UBC Type D)
High Amplification (UBC Type E)
Important: See the accompanying text for an explanation of how these zones were defined and what the various levels of hazard mean.
Astoria-Warrenton
Seaside-Gearhart-Cannon Beach
COLUMBIA
CLATSOP
St. Helens-Columbia City-Scappoose
Hood River
HOOD RIVER
TILLAMOOK
MULTNOMAH
WASHINGTON
Tillamook
YAMHILL
Newberg-Dundee
Sandy
Canby-Aurora
McMinnville-Dayton-Lafayette
Woodburn-Hubbard
Sheridan-Willamina
CLACKAMAS
Silverton-Mt. Angel
Dallas
coln City
Independence-Monmouth
POLK
MARION
Stayton-Sublimity-Aumsville
port
COLN
LINN
Lebanon
0 15 30
Kilometers
Sweet Home
BENTON
Northwest Oregon


Southwest Oregon
Florence-Dunes City
LANE
Cottage Grove
Reedsport-Winchester Bay
COOS
Sutherlin-Oakland
Coquille
Roseburg
DOUGLAS
0 15 30
Kilometers
Liquefaction Hazard Map
Hazard zones are based on the likelihood that liquefaction will occur in a given earthquake.
No Hazard
Low Hazard
Medium Hazard
Highest hazard
Important: See the accompanying text for an explanation of how these zones were defined and what the various levels of hazard mean.
JACKSON
Grants Pass
Ashland
CURRY
Brookings
JOSEPHINE


Liquefaction Hazard Map
Hazard zones are based on the likelihood that liquefaction will occur in a given earthquake.
No Hazard
Low Hazard
Medium Hazard
Highest hazard
Important: See the accompanying text for an explanation of how these zones were defined and what the various levels of hazard mean.
COLUMBIA
CLATSOP
TILLAMOOK
WASHINGTON
MULTNOMAH
HOOD RIVER
YAMHILL
CLACKAMAS
POLK
MARION
LINN
COLN
BENTON
Northwest Oregon